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VACUUM JACKETED UMBILICAL LINES
TECHNOLOGY ADVANCEMENT STUDY

BURST DISCS

AMETEK/Straza
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El Cajon, California 92021

November 1969

CASE FILE COPY

Final Report, Task I
Contract Number NAS 10-6098

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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This report is one of seven similar tasks related to vacuum jacketed components used on the service arms of the launch umbilical tower at Launch Complex 39, Kennedy Space Center, Florida.

16. Abstract

This report is a detailed study of the burst discs installed in the vacuum annulus of cryogenic transfer lines of Launch Complex 39. A search of test history, failure data, and the conditions leading up to the failures that had been experienced in the field prior to, during, and subsequent to space vehicle launch were investigated. Conclusions based on hardware evaluation, product review, new design and comprehensive testing are discussed and recommendations to improve burst disc design and installation are presented.

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FINAL REPORT

For

Vacuum Jacketed Umbilical Lines
Technology Advancement Program
Task I
Burst Discs
Contract Number NAS 10-6098
November 1969

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ABSTRACT

Phase I and II

The NASA Vacuum Jacketed Technology Advancement Program was accomplished in two phases. The Phase I portion of the study (and Technical Report) consisted of four main categories: (1) Hardware Evaluation, (2) Product Review, (3) Design Phase, and (4) Phase II Program Proposal.

The Phase II program portion of the study was also divided into four categories: (1) Preparation of test procedures and procurement specifications, (2) Procurement of test articles and testing, (3) Test reports and related documentation (Procurement Specifications, installation and maintenance procedures), and (4) The Phase I and II Final Report.

Phase I

The Hardware Evaluation Phase evaluated hardware installed in the field. It established the improvements needed in Burst Disc Design. A search of test history, failure data, and the conditions leading up to the failures that had been experienced in the field prior to, during, and subsequent to space vehicle launch were investigated.

Concurrent with this test and failure data search, a Kennedy Space Center on-site evaluation of components and conditions was conducted on Complex 39B. AMETEK/Straza's Inspection Reports (IR) files were also extensively searched for information on damage or failure that would supplement the failure mode analysis being made by the Reliability Engineer.

The Hardware Evaluation and its related activity, which included discussions with field test personnel for launch history, has yielded the data necessary in supporting the design criteria.

The product review phase searched out the present industry-wide state-of-the-art for burst discs and aided in determining present hardware availability.

The design data received from the vendors was evaluated and resulted in the selection of 11 vendors whose hardware exhibited promise to meet the design objectives of the program. This list of vendors was ultimately reduced to six. This selection was based on (1) an expressed desire to assist AMETEK/Straza in development of new designs, and (2) receptiveness to revision to their present product line to meet study objectives.

The Design Phase consisted of establishing the initial preliminary design program objectives which were calculated to increase hardware performance and reliability by overcoming the problems that had been experienced during operational service at Kennedy Space Center.

An analysis was made to determine the maximum flow area requirements of the Burst Disc based on the two most critical line failures than can occur in service.

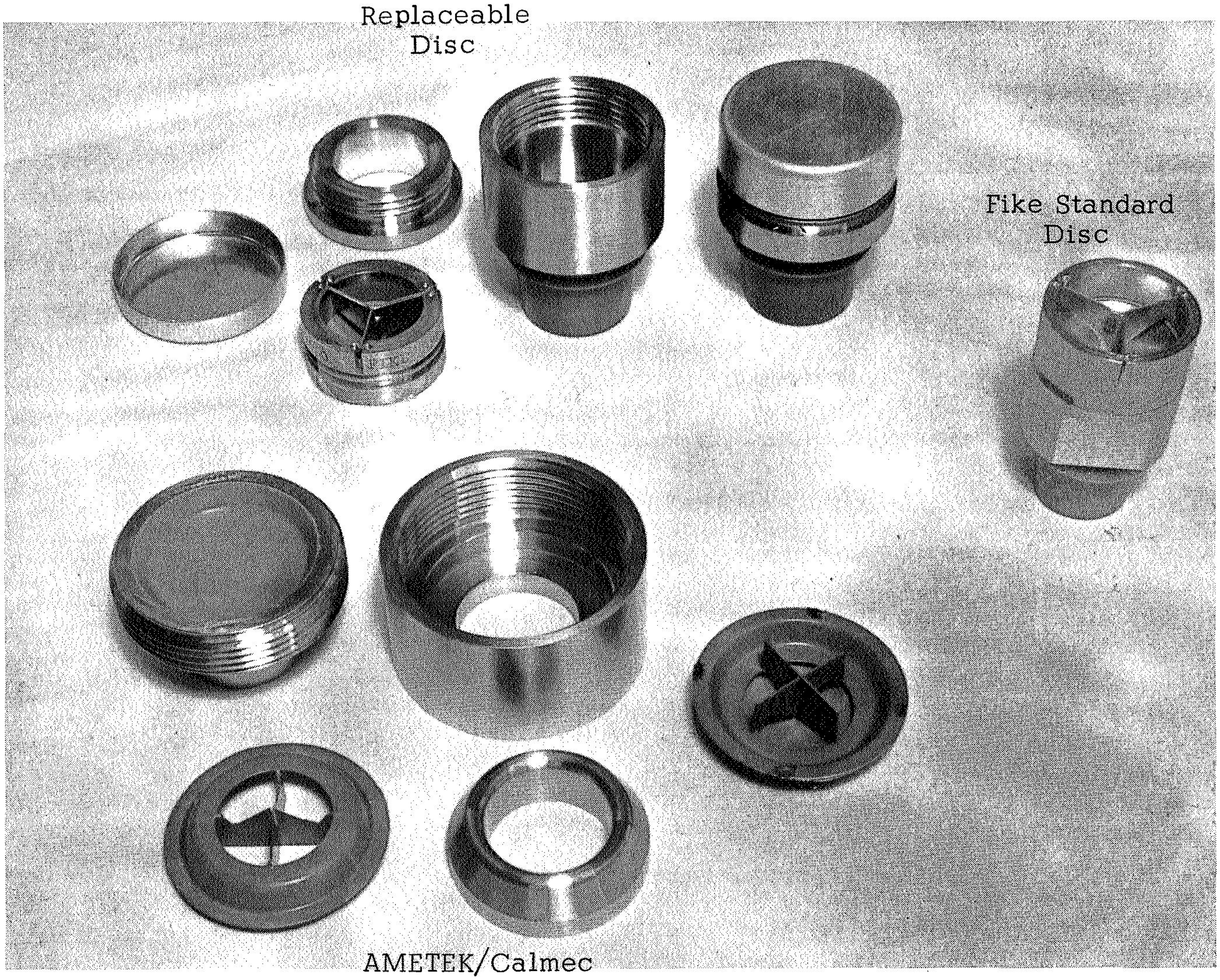
All vendor designs were evaluated through a comparative analysis, taking into consideration such design features as sealing design, flow passage, materials compatibility, simplicity in design and maintainability, burst pressure and tolerance, profile and structural integrity.

This design evaluation was coordinated with the project Reliability Engineer to establish the current state-of-the-art reliability number for burst discs.

The burst disc selected as meeting Phase I study objectives was the "Reverse Buckling" type. See Figure I for photo of tested hardware and Figures 11,12 and 13 for vendor drawings of the burst disc assemblies selected for test.

Phase II

Burst disc specifications were written (KSC No. 79K00108 and KSC No. 79K00109) to incorporate all the design objectives. They included the all-welded unit and the field replaceable unit. Test procedures were written to verify the hardware's capability to operate in the extremes of the natural and induced environments peculiar to the pre-launch and launch conditions at Kennedy Space Center, Florida (KSC). AMETEK/Calmec Company, Los Angeles, California, was selected for procurement, along with Fike Metal Products, Blue Springs, Missouri. In addition, AMETEK/Calmec Company was contracted to perform a burst disc development program. This development program included determining the optimum in (1) disc diaphragm material and thickness, (2) corrosion protective coating for the cutter, (3) bulge height of the disc, and forming parameters affecting part reliability and reverse buckling design. Bare burst disc cutters as well as ones coated were tested in salt fog environment. Coatings included TFE Teflon, Silicone and gold plating. Teflon proved to be superior coating in salt fog tests, although, no parts sustained significant damage due to the tests. The structural integrity of all specimens was verified by completion, without failure, of shock, vibration. None of the tested specimens failed during the salt fog and sand and dust tests.



Burst Discs — Developed By
AMETEK/Calmec and Fire Metal Products

Figure 1. Burst Discs - AMETEK/Calmec & Fike

Test Reports and related documentation were written following the Phase II testing. As a result of the information gained through testing, installation and maintenance procedures have also been written. These procedures eliminate many of the problems that exist on the present hardware.

An analytical method for determining the reverse buckling pressure of the burst disc was completed. This analysis enabled the primary parameters of forming pressure and reverse buckling pressure to be determined by assuming material, material thickness, diameter and dome height. This analytical method provided a technique to calculate the required parameters for a specific application.

CONCLUSIONS

As a result of the Phase I study and Phase II testing represented herein, certain conclusions can be made. These conclusions are briefly stated as follows:

1. The "reverse buckling" disc design has successfully met all the objectives of the KSC study. This design can be applied as a pressure relief device for vacuum jacketed annular space with a high degree of reliability and repeatability.

2. A comparison of the results between the flat seal replaceable disc assembly and the conical seal replaceable disc assemblies demonstrates that the conical seal is superior.

   The flat seat seal is more difficult to seal than the conical seat and the Teflon gasket used in the flat seat is not re-usable due to distortion. This is the result of the extremely high torque required to seal the flat seat unit (600 inch pounds) compared to the conical seat (150 inch-pounds).

3. The all-welded unit proved to be reliable and can be used where field replaceability is not a hard requirement. However, strict quality control should be exercised in the use of any welded detail.

4. A maintenance-free installation can be assured initially by incorporating a comprehensive installation and maintenance procedure. Assembly operations were made successfully (leakage free) on all replaceable disc assemblies by exercising care and clean assembly techniques. The conical seat replaceable assemblies were removed and installed the most times (10) without damage to the disc seal surface.

The leakage-free maintenance operation is enhanced by the use of a thin film of vacuum grease, "Apiezon." This also reduces the torque required to effect the seal on both types.

5. TFE Teflon will successfully inhibit corrosion during salt fog tests. This coating did not affect cutter sharpness nor disc diaphragm rupture tolerance.

6. Dow Corning Silicone "Silastic 55" resists a direct flame at 1400°F for ten (10) seconds. Protective caps for burst discs should be made from the 70 durameter silicone. This protective cap which is expelled at burst should be provided with a retaining device.

7. Thinner disc diaphragm material affords a more completely reversed and perforated diaphragm at burst. Repeatability in burst pressure tolerance is also attained. The thicker disc diaphragm material affords a tighter tolerance of burst pressure; however, reversal and performation of the knife blade is not as complete as with the thinner diaphragm.

8. The outlet disc retainer nut for the replaceable disc assembly should be retained with lockwire or equivalent to eliminate its coming loose during high frequency vibration.

9. The combination of materials tested should be retained: Teflon-coated 17-7PH cutter, Teflon-coated 600 Inconel or 200 nickle disc, 304 L CRES body details.

RECOMMENDATIONS

An analysis of problems associated with burst discs and their installation with particular attention to sealing after disc replacement has been made and the following recommendations are presented for consideration:

1. Additional forming of disc diaphragm material should be accomplished in order to add empirical support to the analytical method for predetermining the reverse buckling pressure on "reverse buckling" disc assemblies.

   This additional forming could be directed toward achieving a closer tolerance between the vendors rated burst pressure and actual burst pressure.

2. It is recommended that additional work be done on the development of the inlet protective device to prevent the disc diaphragm from being damaged during handling.

1.0 FINAL REPORT

1.1.0 PHASE I TECHNICAL REPORT

1.1.1 Hardware Evaluation

1.1.1.1 Functional Review

The Development Item Component functional review task was intended to "review the components' function within the total system requirements as defined by the present system specification" for lines installed on the service arms of the launch tower, Complex 39. (Specifications include 75M06519 and 75M05865 for propellant lines and 75M09783 for vent lines.)

In the early stages of the Study Program, all of the drawings and specifications for the propellant and vent lines installed on the Launch Tower Service Arms were pulled from the AMETEK/Straza files and reviewed by the Project Engineer.

A package of these drawings was prepared for the Project Engineer which was representative of Vacuum Jacketed Lines of every type that AMETEK/Straza had built for installation on the Complex 39 Launch Tower Service Arms.

The requirements on the drawings were compared with the NASA Specification Requirements to ensure that drawings and specifications were compatible. AMETEK/Straza Drawing 8-050035 for the original rupture disc assembly for the vent lines (see Figure 2) was reviewed along with the NASA Drawings 75M8348 Valve, Seal-off, relief which replaced the burst disc.

Acceptance and Qualification Testing was reviewed for compatibility with environmental operational conditions and it was determined that in order to ensure a component's compatibility with environmental and operational conditions, a more comprehensive component testing program is required. (Reference Paragraph 1.1.4)

From the standpoint of Functional Review, it was determined that specifications, hardware, and system were as required and without conflict. From the Functional Review, the conclusion can be reached that hardware maintenance problems exist due to the position of the component on the line and its relative inaccessability. Design changes need to be incorporated into hardware to compensate for blast damage and the Cape environments.

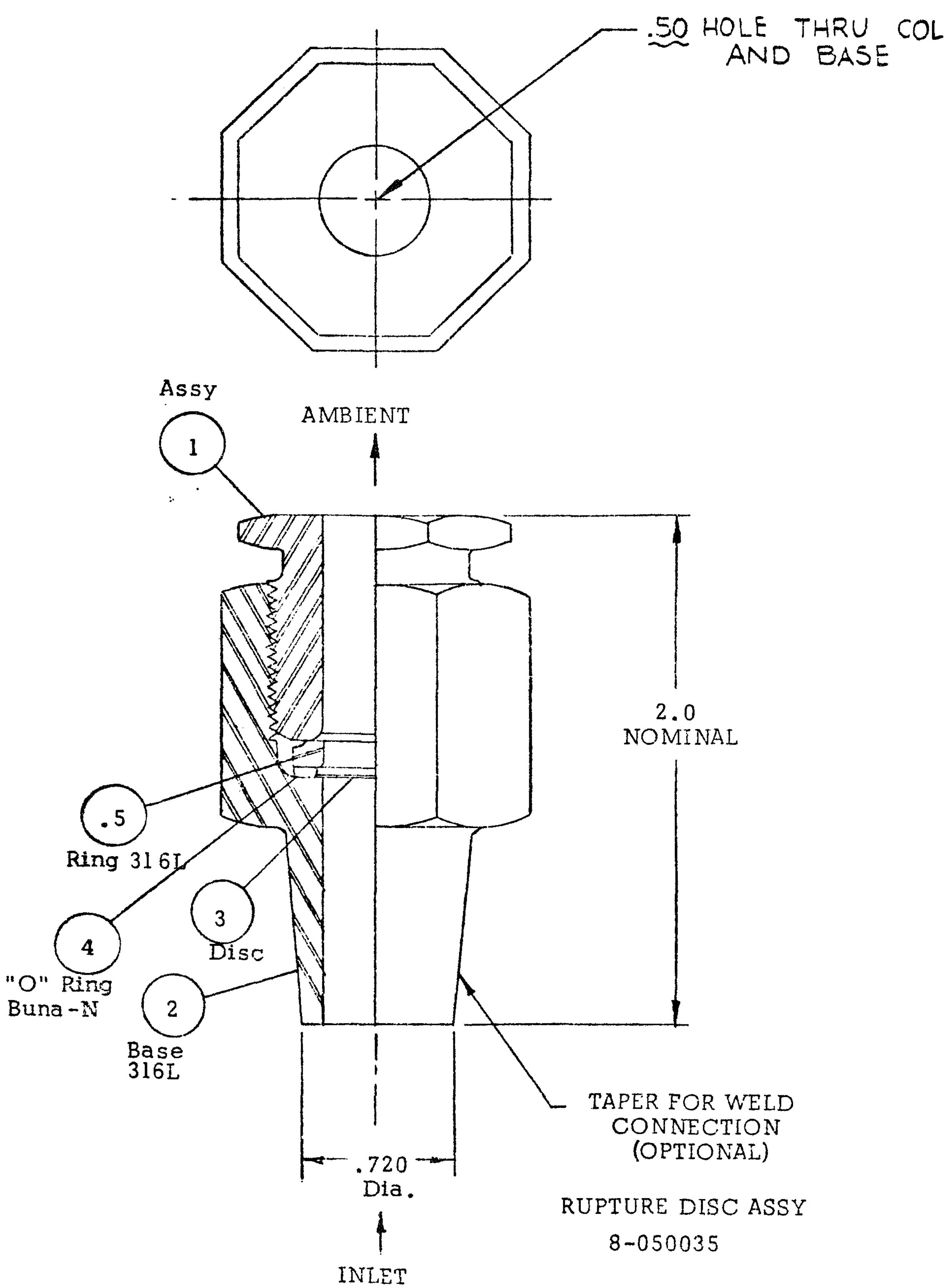


Figure 2. Rupture Disc Assembly

Program Drawing Review

In order to establish the maximum venting requirements for the burst discs, it was necessary to review all of the hardware installed on the Launch Tower Service Arms to determine the "worst case" failure condition based on the existing system line sizes. Each drawing for each line assembly was reviewed to establish the maximum allowable annulus pressure and still maintain line structural integrity. A thorough review of these drawings and related specifications has enabled the Project Engineer to establish realistic design objectives for the NASA study relative to burst disc requirements.

1.1.1.2 Component Operating Requirements

The original vacuum jacketed vent lines installed on the Launch Tower Service Arms at Kennedy Space Center incorporated one half (1/2) inch diameter burst discs. (See Figure 2). This disc was designed to rupture at 25 psig $^{+25}_{-00}$ psig. Operating requirements included temperature range of $-65^{\circ}F$ to $+200^{\circ}F$ and vacuum seal of 1×10^{-4} mm of Hg internally with ambient pressure externally.

Following a failure of a vent line flex hose, these one-half inch diameter burst discs proved to be inadequate to meet the flow requirement. They were removed and replaced with one and one-half inch seal-off/relief valves.

The AMETEK/Straza analysis performed on this program, however, indicates that a one-inch diameter burst disc will accommodate the maximum flow that could result from a failed line.

This valve operator is a rather complex instrument to operate. The Maintenance Procedure V36096, "S-II Intermediate Service Arm Propellant Line Vacuum Monitoring and Maintenance Procedure," was reviewed for clarity, simplicity and content. It was found that the maintenance procedure needed to be expanded to include:

A. More detail in the use of the operator.

B. More instructions relative to cleanliness of both the operator and the valve;

C. Cautions relative to the complexity of vacuum components and systems;

D. Instructions that will reduce the chance for external contamination and/or damage.

The present hardware was examined to determine the modifications that could eliminate the problems of residual leaks and poor resealability which has necessitated excessive maintenance operations. These modifications could include:

A. Elimination or improvement in the electro-coating of the valve plug (NASA No. B75M08348-23). Particles are being deposited on internal surfaces of the valve.

B. Improvement in the guide portion of the Valve Disc (NASA No. B75M08348-27). The guide is causing excessive wear on the side of the valve and metal particles and/or residue could be deposited on valve sealing surfaces.

C. The addition of a filter to eliminate foreign particles being drawn up into the valve from the annular space (i.e., dexter paper, metal particles, etc.).

In summary, an improved maintenance procedure and several design changes in the present hardware would result in a definite improvement in hardware performance. It has been a prior philosophy that vacuum components should be constructed so as to avoid problems while being serviced by personnel unfamiliar with vacuum equipment. It is strongly recommended that a strict instruction period and certification be maintained for all personnel who work and maintain components on vacuum systems.

1.1.1.3 Evaluation of Equipment & Conditions

This task was intended to determine if problems presently being experienced with the component are associated with their installation and/or removal of the component from the system.

An on-site review was made at both Huntsvil'e and Cape Kennedy for an evaluation of conditions and the gathering of study related data and reports. Following each trip, a general meeting was conducted of all program personnel to inform them of the trip results and review the data returned to the plant.

As a result of the on-site investigations, the following conclusions were reached relative to the equipment and conditions:

A. Burst discs are subjected to severe corrosive environment (salt fog) with a lack of lubricant on critical areas to preclude rust.

B. Seal-off/relief valve combinations installed in the field are operating in accordance with system requirements. The problem of hardware fragility is reflected in damage incurred during maintenance operations. The location of components on the line, however, is not making maintenance operations an easy task.

C. The components should be designed to absorb external damage without malfunction.

D. The location of line components on the Service Arms make it extremely difficult to service and contribute to the problem experienced during maintenance operations.

During the course of the Hardware Evaluation Phase of the study, it was possible to evaluate several of the Launch movies taken on Pad 39B. These movies aided in establishing the relative severity of structural and vibratory loads inflicted on the Service Arm hardware during an operational launch. Several design improvements have been proposed as a result of this information. One is a protective cover to protect the disc from the vehicle engine heat during lift-off.

The on-site review afforded AMETEK/Straza engineers with a working knowledge of site conditions which made it possible to request data and better evaluate design improvements for the design development items.

1.1.1.4 Review of Failures

This task required a review of all available data delineating problems encountered during operational service. It consisted of a review of all conditions to which the system is subjected, and was performed concurrently with the review of test data.

The following tab runs, Boeing "Unsatisfactory Condition Reports" were obtained from Cape Kennedy for review: 676-8, 676-7, 676-10 and 676-2. This failure history helped to establish the failure mode analysis described in Section 1.1.3.4.

The Kennedy Space Center Review Team reported that damage potential exists due to mishandling and standing on the V.J. lines. This is an inherent characteristic due to the location of components and the precarious position the mechanics place themselves in to maintain this hardware.

Approximately twelve hundred (1200) Straza Inspection Reports (IRs) for lines received for rework were reviewed. The results include:

A. Only two (2) IRs were applicable to the present hardware.

B. Tab runs indicated three failures as shown in Table 3, Paragraph 1.1.3.4.

The list of failure modes was compiled after review of all the available data and failure mode analysis and is defined as the existing hardware reliability number.

1.1.1.5 Review of Test Data

In the field of burst discs, very little test data exists. Each vendor that was solicited for hardware designs was asked to include all available reliability and test data related to their particular hardware. Each vendor emphasized that there was no test data available for burst discs. Reliability information was also not available.

In order to establish a substantiation for the failure modes analysis, several vendors were called for information on where their customer or burst disc user had experienced problems or where the suppliers themselves would expect problems. In all cases, corrosion of the thin disc diaphragm was expected to be the greatest failure mode. The second most serious problem was damage to the thin diaphragm material during installation and/or maintenance. They stated that several other problems exist of a less serious nature including:

A. Damage inflicted by the force of a blow to the structural body. This could cause wrinkling if the disc diaphragm is extremely thin.

B. Rusting of the knife blade cutter which affects the burst pressure tolerance. This is a function of the severity of corrosion. Tests will be conducted on teflon-coated specimens during the Phase II program to verify elimination of this problem.

1.1.2 Product Review

1.1.2.1 State-of-the-Art Investigation and Vendor Coordination

The product review for burst discs was performed concurrently with the hardware evaluation phase of the program. When enough significant test data, failure history, failure mode information, and reliability information became available through the hardware evaluation, the study design objectives were established and the various hardware vendors contacted to discuss the program and establish their interest in the NASA study. The product review has produced information an all of the burst discs available on the market. A review of the literature on the subject that was available has given us confidence that a good representation of hardware is provided.

The VSMF was utilized to establish a preliminary list of burst disc manufacturers. This preliminary list was expanded by adding the manufacturers found in the current Cryogenic and Vacuum Technology publications. AMETEK/Straza's vandor search did not initially set a standard on any vendor's capabilities. Everyone who had hardware experience related to burst discs was solicited for information. Interest in the program and a desire to work with us to develop an improved burst disc was expressed by several vendors.

The literature that was reviewed established the different types of burst discs presently being manufactured by leading vendors.

Burst disc manufacturers, a total of 40, were contacted; 11 were selected as having the hardware that would lend itself to modification to meet study objectives. Also, these 11 vendors had expressed an interest in the study program and a desire to develop a design that would eliminate the problems attributed to burst discs. These vendors include:

A. Aervalco, Los Angeles, California

B. Black, Sivalls and Bryson, Incorporated, Kansas City, Missouri

C. AMETEK/Calmec, Los Angeles, California

D. Continental Disc Corporation, Blue Springs, Missouri

E. Carbone Corporation, Boonton, New Jersey

F. Consolidated Precision Corporation, Lake Park, Florida

G. Cryolab Company, Los Osos, California

H. Fike Metal Products Corporation, Blue Springs, Missouri

I. Kearney Industries, Raritan, New Jersey

J. Parker Aircraft, Los Angeles, California

K. Whittaker Corporation, North Hollywood, California

These hardware manufacturers (all leaders in the field of burst discs) afford a good representation of the manufacturers of the various types of discs that are available on the market today.

A review of the vendor data received resulted in the selection of six vendors. Their selection was based on the vendors' desire to develop a new design or incorporate modifications in their hardware that would result in improvements over the burst discs available on the market today. These six vendors include:

A. AMETEK/Calmec

B. Black, Sivalls and Bryson

C. Cryolab Company

D. Fike Metal Products

E. Parker Aircraft

F. Whittaker Corporation

1.1.2.2 <u>Hardware Investigation</u>

1.1.2.2.1 <u>Evaluation Check-List-Vendor Survey</u>

During the initial stages of the vendor contact, it became evident that the hardware vendors' capability in fabrication was extremely important. For this reason an evaluation survey was conducted for each vendor listed. This Quality Survey consisted of a review of the vendor's capability including:

A. The vendor's product

B. Marketing-Engineering effort

C. Manufacturing

D. Testing, and

E. Quality Assurance

A review of the vendor's product served to establish if this type of equipment had been previously designed or made to print by the vendor.

Marketing-Engineering capability established whether the vendor was directed toward commercial rather than government contracts.

The vendors' manufacturing capability established the vendors' capability for the manufacture of cryogenics, testing, and whether clean room facilities existed. It also confirmed the status of welding controls and equipments and radiographic inspection.

Testing — This evaluation established the equipment available for testing, fluids used, calibration, and conformance to industry standards.

Quality Assurance — This evaluation established the vendors' Quality Control system and the specifications the vendors' Quality Control system conforms to.

1.1.2.2.2 Evaluation of Burst Disc Types

The following is a description of all of the types of burst discs evaluated through the product review. Every type was evaluated for the possibility of adapting various designs into study hardware. This description includes the most basic to the most complex burst discs available in the industry today.

Burst Disc Body Types

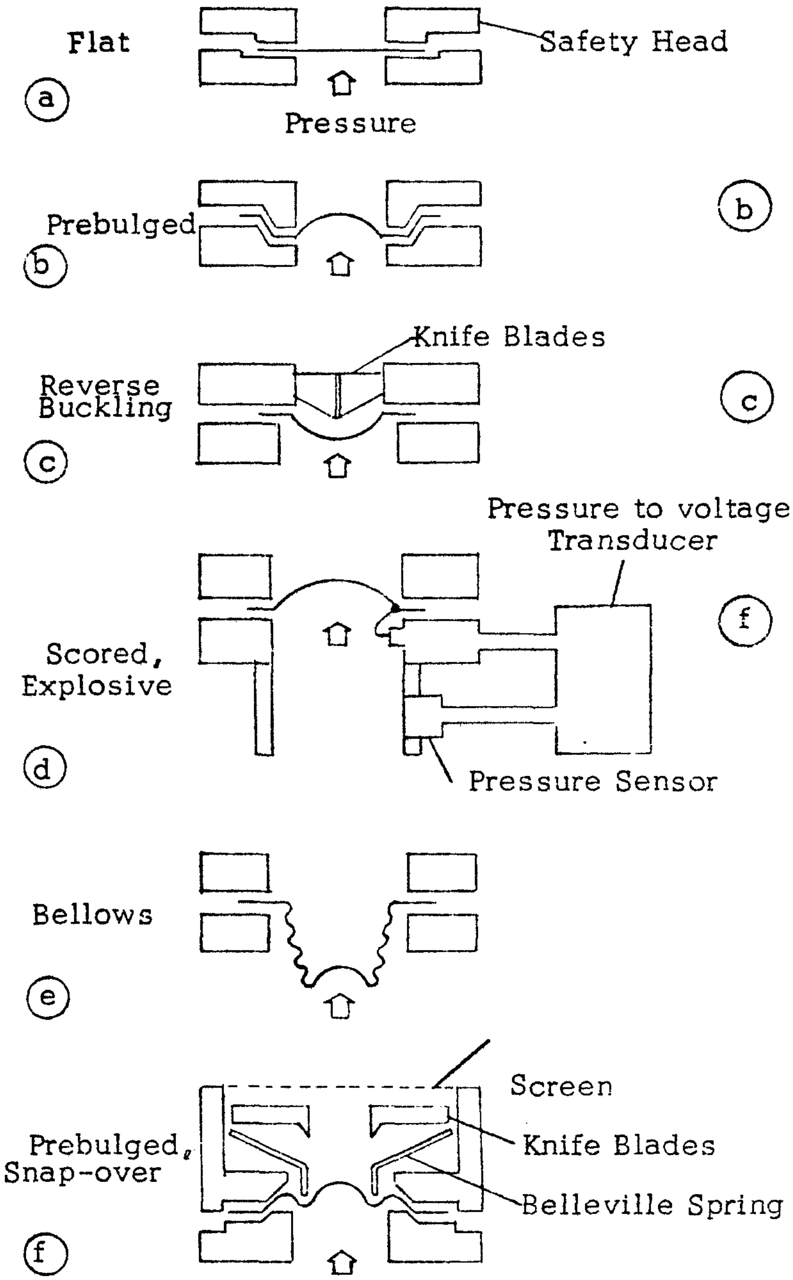
A. Bolted Type

The bolted type burst disc assembly is available in diameters ranging from 1/2-inch to 24 inches with standard ASA flange bolting. The angular seat assures a gas tight seal with minimum torque loadings applied to the studs. This eliminates flange and seat distortion and thereby protects the precision rupture disc against slippage under pressure and shearing of the thin disc material. Standard material for the flanges is steel, but can be supplied in other metals. Standard flange connections are threaded, welding hub, or flat face with preassembly cap screws. The bolted assembly may employ prebulged, flat, scored, reverse buckling or other diaphragms.

The bolted type burst disc does not lend itself to this program due to large profile and long assembly/disassembly times (see Figure 3, a through f).

DESIGN EVALUATION
TYPES OF BURST DISCS

VENDOR AVAILABILITY



Various Styles of Metal Rupture Discs

(a) Fike
BS & B
Continental
Carbone *
Whittaker
Aerovalco
Calmec

(b) Fike
Continental
Consolidated Precision Co.
BS & B
Kearney

(c) Continental
Fike
Consolidated Precision Co.

(f) Calmec
Parker Aircraft

* Impervious Graphite

Figure 3. Types of Burst Discs

B. Union Type

The union type assembly is similar to the standard pipe union except that it has the precision angular type seat machined into the inlet and outlet connections in order to grip the rupture disc the same as in the bolted type assembly.

The union type units are compact and easier to maintain than the bolted type unit of comparable size and lends itself to ground support and/or airborne hardware. As it can be noted, all standard disc diaphragms can be incorporated into the union assembly (see Figure 3, a through f, and Figure 4).

C. Screw Type

These units are used primarily for the protection of laboratory and experimental pressure equipment. Since they are a small compact unit with the inlet constructed of stainless steel as standard, they can be used for many applications where small volume and high pressure is involved. The screw type also utilizes the angular seat. These discs can provide extremely thin disc diaphragm material because of the protection from the natural environments. This type generally screws into a boss and has been used in the past for ground support vacuum jacketed lines. This unit has a thin diaphragm whose sealing surface can be rotated during assembly. The seal movement frequently causes seal leakage. This defect makes this standard screw type unit configuration unacceptable as a study solution.

Types of Discs

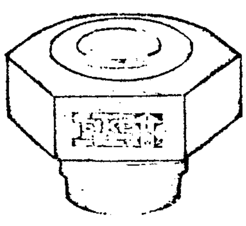
A. Flat Rupture Discs (Metal)

Flat rupture discs were investigated for applicability to the study. In general, the disadvantage of the flat rupture disc is that they bulge when subjected to pressure in an installation. Since the shape of the bulge is not an exact spheroid, the disc is stressed unevenly and may then burst unpredictably.

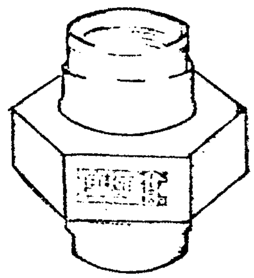
It has been found that flat rupture discs are used extensively in fire extinguishers and in valves for compressed gas bottles to protect against overpressure if high temperatures are encountered. The flat rupture disc is usually designed to shear against a sharp radius to assure a full opening and unrestricted flow of the fluid or gas to be relieved. The most commonly used disc materials for this application include a combination of gold and beryllium, copper or nickel (see Figures 3 and 5).

Fike Union Type Rupture Units

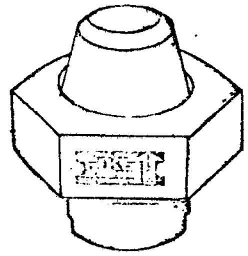
The union type rupture units illustrated below are adaptable to pressure system piping. The union type units are compact and easier to maintain than the bolted type unit of comparable size. The standard material for these units is carbon steel; however, other material combinations are readily available on request. To order any of the units listed below give the size, assembly letter, pressure rating, and material required if other than the standard carbon steel. Order rupture discs separately and specify union type assembly letter, size, material, and rupture pressure.



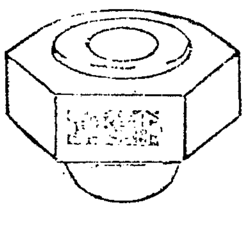
ASSEMBLY AU
Threaded Base
Flat Holddown



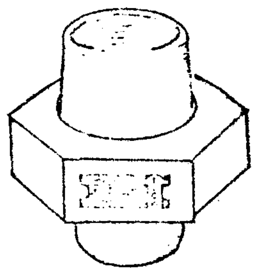
ASSEMBLY BU
Threaded Base
Threaded Holddown



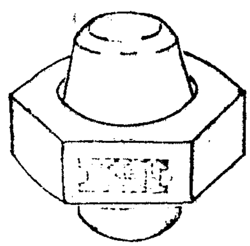
ASSEMBLY CU
Threaded Base
Welding Holddown



ASSEMBLY DU
Welding Base
Flat Holddown



ASSEMBLY EU
Welding Base
Threaded Holddown



ASSEMBLY FU
Welding Base
Welding Holddown

TABLE 7

PIPE SIZE	MAXIMUM RATING PSI AT 100°F	WIDTH ACROSS FLATS	APPROXIMATE HEIGHT IN INCHES					
			AU	BU	CU	DU	EU	FU
1/2	3000	1 3/4	1 11/16	2 3/8	2 1/4	1 11/16	2 3/8	2 1/4
1/2	6000	2 1/2	2 1/8	2 5/8	2 5/8	2 1/8	2 5/8	2 5/8
3/4	3000	2 1/2	1 7/8	2 3/4	2 1/2	2	2 7/8	2 5/8
3/4	6000	2 3/4	1 7/8	2 3/4	2 1/2	2	2 7/8	2 5/8
1	3000	2 3/4	2 1/8	3 1/8	3 1/16	2 1/8	3 1/8	3 1/16
1	6000	3	2 1/4	3 1/8	3 1/16	2 1/2	3 3/8	3 5/16
1 1/2	3000	3 1/2	2 5/16	3 1/4	3 1/8	2 1/2	3 1/2	3 3/8
2	750	5	2 11/16	3 7/16	3 7/16	2 7/8	3 5/8	3 5/8

FIKE METAL PRODUCTS CORP. Blue Springs, Missouri, U.S.A.

Figure 4. Fike Union Type Rupture Discs

B. Flat Rupture Discs (Carbon)

Flat carbon rupture discs are common in the chemical industry and have two desirable inherent properties: (1) Changes in temperature do not affect the burst pressure of the disc; (2) carbon withstands most corrosive processes. The main limiting factor of the carbon disc for industry usage is the maximum pressure rating for which they can be manufactured. Generally, these discs can only be used for pressures of 300 psig or lower which is within the range of the NASA study. Their accuracy is ±5% and are less expensive than a pre-bulged or flat rupture disc in the lower pressure ranges.

They are completely unaffected by fatigue and possess complete immunity to thermal shock. Serveral advantages are: Maximum flow opening is obtained at actuation, low costs for parts and maintenance, and the non-fatigue nature of graphite allows continuous operation at up to 75% of rated pressure.

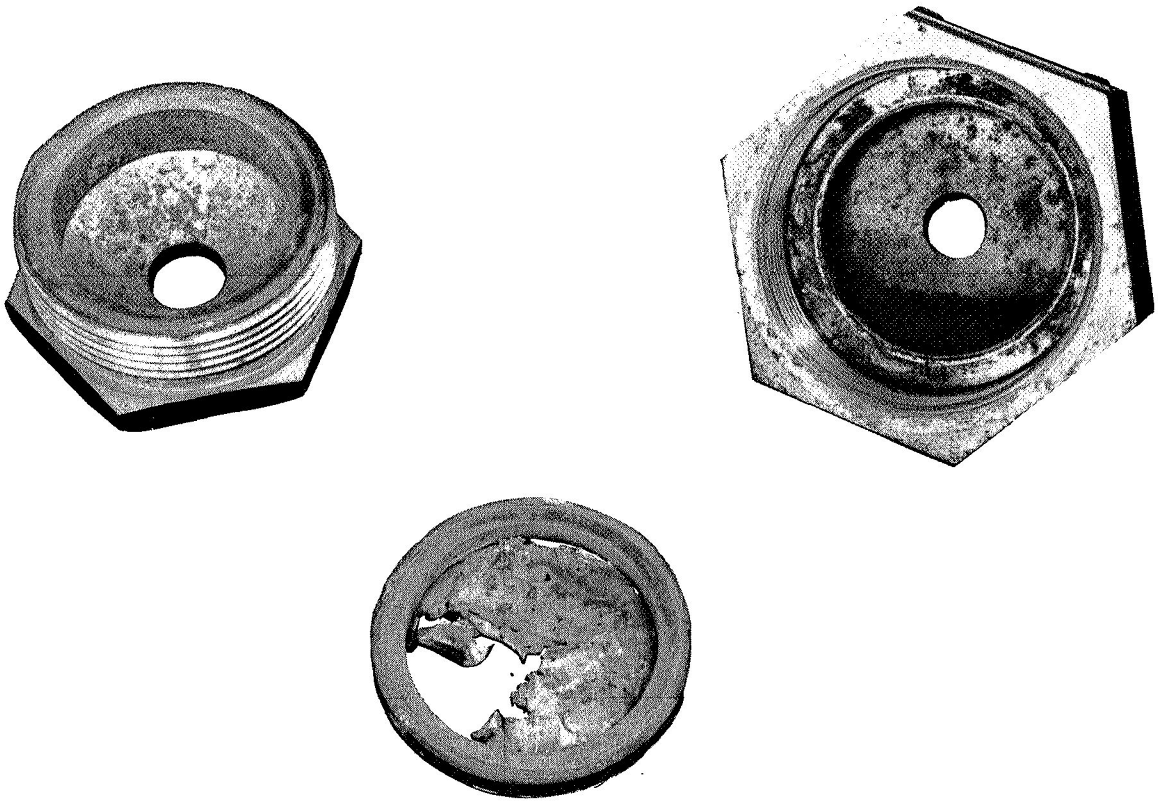
The Carbone Corporation of Boonton, New Jersey, submitted two samples of their carbon disc hardware along with related test and design data (see Figure 6). A burst disc of this type would require installation between two flanges. This design principle was rejected because the burst disc assembly could not meet the low leakage allowable of 1×10^{-7} scc/sec of helium. A test recently conducted at AMETEK/Straza indicated that the carbon disc leaked at a rate of 1×10^{-5} scc/sec.

C. Pre-bulged Rupture Discs

These burst discs are pre-bulged to operate at approximately 70% of rated burst pressure without deformation. That is when a pre-bulged disc is rated to burst at 40 psig and is installed on a vessel, the operating pressure of the vessel can safely range to 28 psig. If the 70% margin is exceeded, then reduced rapidly, the disc will work harden. This causes premature or inaccurate rupture of the disc at time of rupture.

Materials commonly used for this type of disc include aluminum, CTFE Fluorocarbon, TFE or FEP Fluorocarbon, Monel, Inconel, 347, 321, 316 Stainless, Nickel, Copper, Gold, Silver, Platinum, Titanium and Tantalum.

Temperature variations also change the burst pressure of the pre-bulged disc which are rated at 72°F and since temperature is inversely proportional to the burst pressure of a metal disc, burst pressure changes according to actual process operating temperature. The pre-bulged disc requires protection from vacuum by use of a vacuum support (see Figure 7).



Flat Rupture Disc
(Failure of Diaphragm Due to Corrosion)

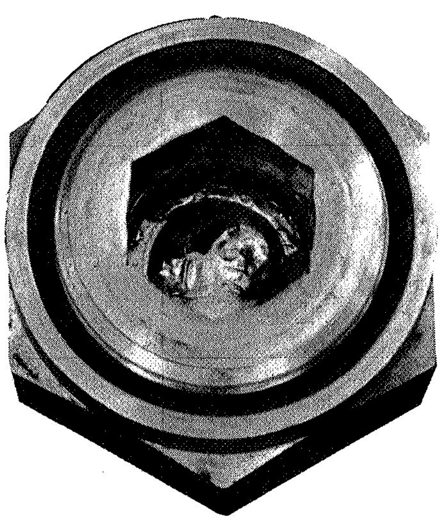


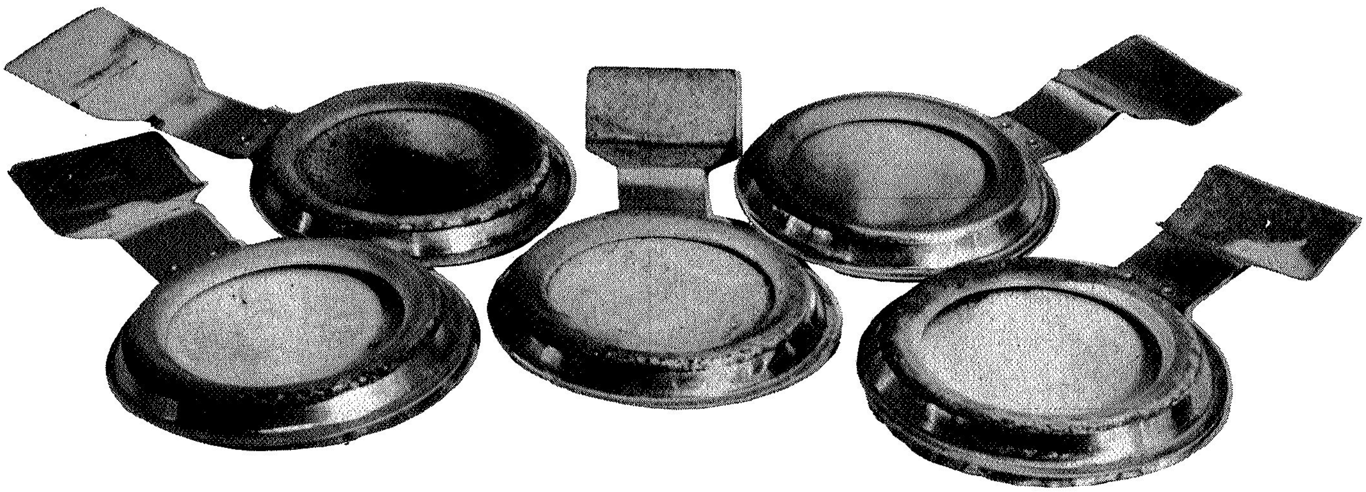
Figure 5. Flat Rupture Disc

2-1/2 In. O.D. x 1 In. High
Burst Disc to be Installed
Between Mating Flanges

1 In. Dia. Flow Opening
Burst Pressure
Max. 26.25 psi
Min. 23.75 psi

Carbon Rupture Disc
(Courtesy of Carbone Corporation)

Figure 6. Carbon Rupture Disc



Note Sealing Surface
Unaffected by Corrosion
Burst Press — 32 psia

Aluminum Pre-Bulged Rupture Disc
(Removed From A Vacuum Jacketed Storage Vessel)

Figure 7. Pre-Bulged Rupture Disc

D. Scored Rupture Discs

Scored rupture discs and their applications were reviewed for use in the study program. Recommended where disc fragmentation cannot be tolerated, this type of disc is made to rupture at a specific pressure by grooving or milling the material. This disc can be either flat or prebulged and can be scored in a number of ways to meet various applications.

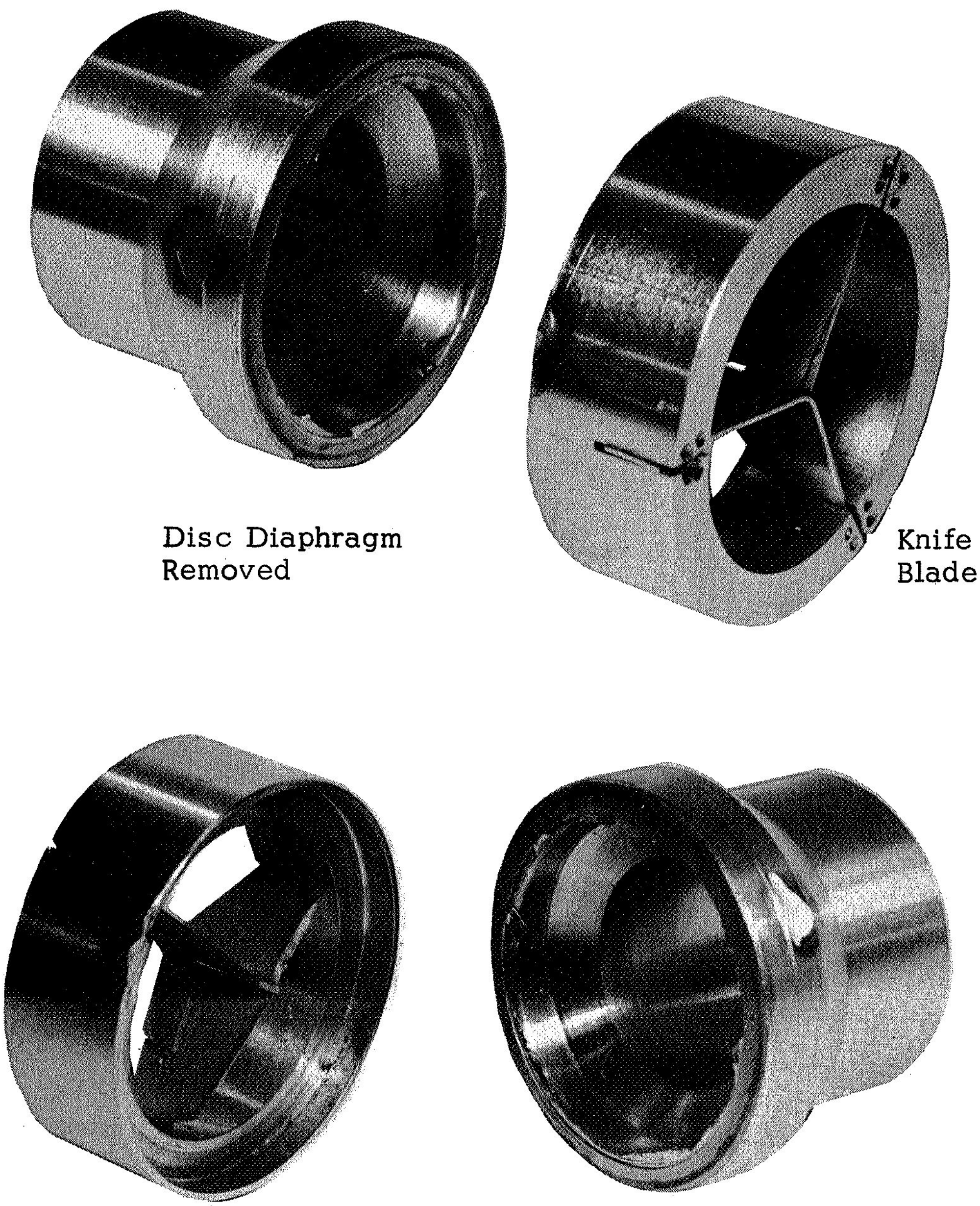
For example, discs are scored in X and Y patterns, in straight lines, or in circular rings. Also, they may be machined or milled to a dimension which will provide the required rupture pressure. Very few scored discs are used today due to the precision notching which is required to obtain the exact rupture pressure. For instance, a scratch 0.0001 inch deep on the face of a disc can change the burst pressure several pounds per square inch.

Scored discs have been used successfully as quick opening valves, and in applications where sudden pressure releases are required such as in shock tubes. Sudden pressure releases are also used to impose extreme shock on parts undergoing test, or to quench runaway process reactions.

E. Reverse Buckling Rupture Discs

Reverse buckling rupture discs have all the inherent properties of a prebulged disc, but the means of rupturing the disc is different. Instead of the material being stretched to rupture (as in a prebulged disc), it is compressed to a point of buckling through the bulge and thrown against knife blades welded to the upper body assembly. This action cuts the disc into pie sections. The best features of this type disc are: (1) There is no need to use a support in a vacuum system; (2) the disc permits operating pressure to approach 90% of rated burst pressure; (3) there is little or no fragmentation of disc material upon rupture; (4) the diaphragm material can be much thicker for the same burst pressure for increased ruggedness and corrosion resistance (See Figures 3 c, 7and 8).

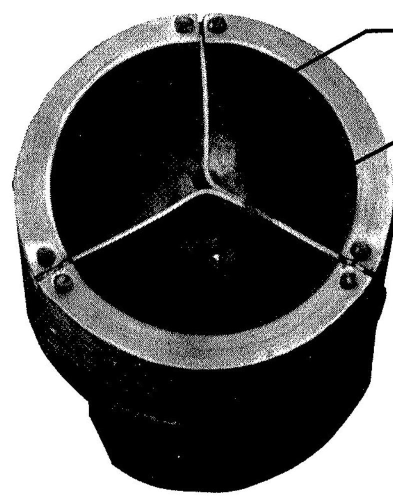
The design phase (Section 1.1.3) describes the fundamental principles of this design. Basically, this type of burst disc incorporates a unitized construction as well as a replaceable disc diaphragm assembly. This type of a unit can be an all welded construction or it can incorporate a soft copper or elastomer gas-



Knife
Blade
3/4 In. Dia. x 1-1/2 In. Length

Reverse Buckling Rupture Disc
(Disc Diaphragm Removed)

Figure 8. Reverse Buckling Rupture Disc



1/2 In. Dia. x 1-1/2 In. Length

Reverse Buckling Rupture Disc With Failure
Of Diaphragm Due To Corrosion

Figure 9. Reverse Buckling Rupture Disc Failure

ket for the seal between the disc diaphragm assembly and main body.

The "reverse buckling" burst disc offers several distinct advantages including:

(1) Capability for easy replacement in the field. However, since the thin disc material has potential for damage at installation, the inlet and outlet sides of the disc should be protected. The cutter blades at the outlet provide this protection. At the inlet side, a mechanical device similar to a screen is recommended.

(2) Capability as an all welded unit. This offers a relatively high increase in reliability by eliminating all metal or elastomer seals that require care in assembly and field maintenance, and that could be affected by variations in operating conditions.

(3) Elimination of handling the thin disc material during assembly and/or maintenance will result in an increase in reliability.

(4) This design also offers the capability for a very low profile unit that provides exceptional ruggedness for handling and service.

F. Prebulged, Snap-Over Rupture Discs (Belleville)

This type of disc design is a standard prebulged type. Like the reverse buckling unit, the means of rupturing is different. These units have a Belleville spring which rests on the convex side of the bulge.

When pressure moves the disc, the spring snaps over, throwing the disc against a circular cutting ring. This cutting arrangement is now even more commonly used with flat discs than with the prebulged discs. The cut-out disc center (if it is an in-line installation) goes down the pipeline and is caught by a screen. These units are accurate, but expensive, in comparison to a standard prebulged or flat disc, and are used mostly in aircraft and missile applications. (See Figure 3b)

The two companies that have perfected this design and who appear to be supplying all of this type of burst disc are AMETEK/Calmec and the Parker Aircraft Company (both in Los Angeles, California).

Parker Aircraft has designed and supplied Belleville spring burst discs for the L.E.M. (Lunar Excursion Module) of the APOLLO Program. They are used to prevent excessive pressure in the astronaut oxygen supply system. Another is used to insure zero leakage of helium gas from the main propellant tanks. AMETEK/Calmec has applied this concept for North American Rockwell as a relief valve for the fuel pressurization system in the Attitude Control System (A.C.S.), Service Propulsion System (S.P.S.) and for NASA, Huntsville, in the Auxiliary Propulsion System for Post APOLLO.

The Belleville Spring concept solves several of the problems that had been experienced in the burst disc being used by NASA, such as corrosion of the thin metal disc, and damage of the thin disc diaphragm during replacement. These failure modes would be eliminated by virtue of the fact that: (1) Rupture settings are not affected by diaphragm material. The hollow punch or cutter makes possible the burst diaphragm that is less dependent on material strength. For this reason, a reasonably thick, stainless material can be used; (2) plastic coating of the disc material for extra protection from corrosion can also be used without affecting the burst pressure tolerance. The application of the Belleville Spring into study hardware was discussed with both AMETEK/Calmec and Parker Aircraft. Evaluation of their design was made and several specific design improvements were incorporated into the Belleville design which included:

(1) The burst diaphragm would be seal welded to the upper disc assembly body to eliminate a leakage path.

(2) The burst disc assembly would be made up of a removable disc assembly and a base that would be welded to the vacuum jacketed line. The disc assembly would be replaceable by simply removing the present disc assembly and "dropping in" a new one into the base and clamping it down.

(3) Sealing between the base and the replaceable disc diaphragm assembly would be affected by an elastomer "O" Ring and a clamp that would apply a uniform load around the entire periphery of the disc base.

During the design reviews, it was brought out that several general design improvements were offered by the Belleville design concept. These design features included:

(1) Stability over a broad range of operating temperatures. It can be proven analytically (and by test) that the burst accuracy depends on the modulus of elasticity of the spring member rather than ultimate strength. Therefore, burst variation due to temperature change is very slight. (For the hardware that was proposed by AMETEK/Calmec, the variation in burst pressure is 4% or about 1.2 psig total, a factor which is not critical due to the burst pressure band for present design parameters.)

(2) Reduction of pressure cycling effects. Since this unit can operate to within 95% of the rupture rating and can withstand repeated cycling, each assembly can be pretested for rupture without damage to the burst diaphragm. This unit can also be rechecked at any later date after they have been in service.

Both the AMETEK/Calmec and the Parker Aircraft Belleville spring designs were rejected as candidates for Phase II test by virtue of failing to meet Phase I study objectives.

The AMETEK/Calmec unit exhibited a very low profile in the installed position (one and one-half inches). This low profile was negated by a very large diameter (approximately 4.00 inches)(See Figure 10). The low actuation pressure requirement 30 ±5 psi required that the surface area of the Belleville spring be large in

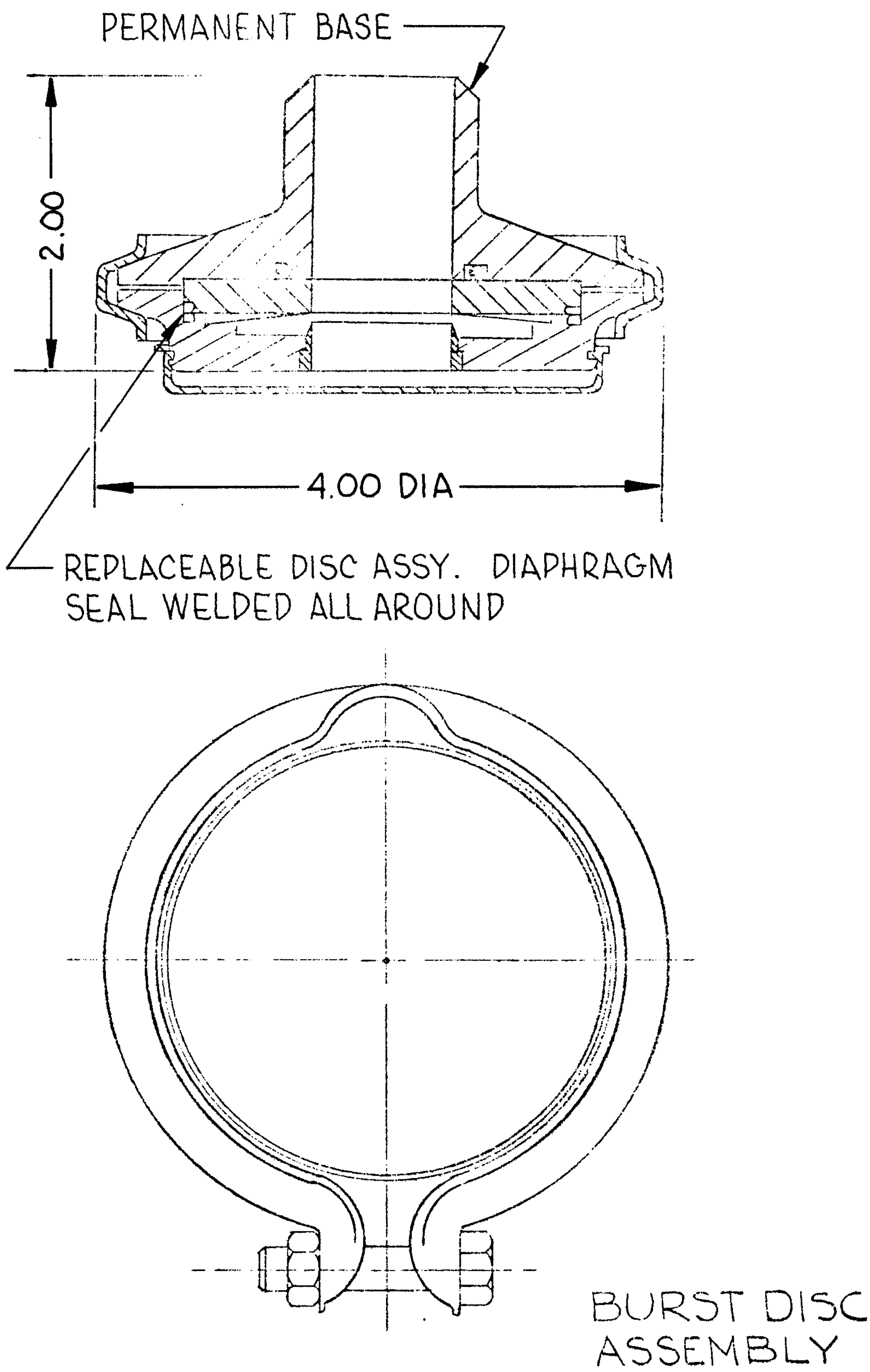


Figure 10. Belleville Burst Disc Assembly

order to provide the snap-action at this low pressure. The large diameter presented no particular physical problems in installation, but it did rate low in reliability due to corrosion of the excessive material in the large diameter.

Another design deficiency appeared to be the clamping device for retaining the replaceable upper disc diaphragm assembly to the base (the base is welded to the vacuum jacketed line). (See Figure 10)

This clamp created several moisture traps between the clamp and the disc assembly. The clamp was adequate to effect the seal between disc assembly and base, but again it was the potential for corrosion that made it rate low in the reliability analysis.

Cutter-Belleville Burst Disc

The round cutter on the periphery of the disc diaphragm was considered to be unreliable due to the effects of corrosion on the cutting edge. The Calmec Belleville Cutter is fabricated with a "saw tooth" edge which is required to effect the cutting action upon burst. However, it was found, during the study, that this cutter requires extensive maintenance and sharpening to the cutting edge to maintain its cutting efficiency.

Reliability Trade-Off Analysis
(See Section 1.1.3.4 for Detail Analysis)

A Reliability Trade-Off Analysis was conducted by the Reliability Engineer to establish the Belleville spring concept as compared to the "reverse buckling" disc that is recommended for this study. The analysis is shown in the Reliability Section. In summary, the reverse buckling concept is a more simple, rugged design which is less susceptible to external and disassembly damage, corrosion, and "O" Ring problems.

The outlet diameter of the "reverse buckling" disc is increased to allow for the added surface area for the added assurance that the disc diaphragm will not restrict flow after rupture.

G. Alumiseal Seal Flanges

The Whittaker Corporation (Vacuum Systems Division) submitted a design for a flat rupture disc which incorporated the use of their Alumiseal Bakeable Flanges. Both the Whittaker Corporation and Varian Associates recommended the use of flanges in the vacuum components for ease of maintenance.

The flanges are a simple, reliable metal gasket seal design. (The gasket can be any non-corrosive material). These seals permit prolonged temperature excursions from liquid Nitrogen temperature to $450^{\circ}C$. The flange owes its ability to withstand the thermal cycling to its unique design.

Mating flanges are identical with seal surfaces machined at slight spherical angles. As the bolts are tightened, the flanges rotate until opposing seal faces are nearly parallel. The gasket material is loaded at 2000 to 3000 pounds per linear inch of gasket and strain energy is stored in the rotated flanges.

This stored energy prevents flange unloading caused by thermal changes. The flange design has the added advantage of using standard stainless steel bolts. While 0.0015 inch thick stainless steel foil is the standard sealing material, household 0.008 inch aluminum foil has been found to be quite adequate for special applications. The Whittaker Corporation has designed and built a burst disc which is presently used on their Cryosorption Pump which provides venting capability during the bake-out cycle.

The Whittaker design, even though possessing a very adequate seal, was rejected for several reasons, including:

A. An adjustable screw (cutter) which is used to effect the initial perforation of the .002 inch stainless steel disc;

B. The disc also serves as the metal gasket seal.

It has been an objective of this program that the burst disc will provide an installation that is relatively tamperproof. An adjustable cutter for such a critical design feature precludes the use of this design.

Another objective of the study program has been to provide a disc assembly which will eliminate the handling of the disc diaphragm material during replacement or maintenance.

1.1.2.2.3 Comparative Analysis - Burst Discs

The following comparison of vendor products represents the industry standard for usage of materials and design application for burst discs used as relief devices for overpressure in vacuum annulus. These lists, as they have been expanded

Table 1. Comparative Analysis of Burst Discs

Vendor	Type	Diameter (Inches)	Sealing Method				Configuration	Corrosion Protection	Flow Passage	Interface	Burst Press	Leakage Allowable scc/sec He	Method Of Replacement	Simplicity in Design			Profile	Reliability
			Main Seal	Disc Seal	Cap Seal	Seal Redundancy								Design	Operation	Maintenance		
AMETEK/Calmec	Belleville Spring	1	"O" Ring Buna-N	Weld	"O" Ring Plastic	None	Elastomer "O" Ring	Moisture Traps Exist	Flow Area Unobstructed	Weld to Line	30 ±5 psig	1×10^{-7}	Simple	Complex	Simple	Simple	Exceptionally Low	Poor
AMETEK/Calmec	Reverse Buckling	1-1/2	Copper Gasket	Weld	"O" Ring Plastic	None	Copper Gasket	Protective Cap And Sealant	Obstructed By Diaphragm Flow Area Same	Weld to Line	30 ±5 psig	1×10^{-7}	Simple	Simple	Simple	Simple	Low	Good
Aervalco	Union Type Burst Disc	1	Weld	Weld	"O" Ring Plastic	None	Elastomer "O" Ring	Protective Cap And Sealant	Obstructed By Diaphragm Flow Area Reduced	Weld to Line	100 ±5 psig	1×10^{-6}	Simple	Simple	Simple	Difficult	Low	Poor
Consolidated Precision	Union Type Burst Disc	1	Weld	Weld	"O" Ring Plastic	None	All Welded	Protective Cap	Obstructed By Diaphragm Flow Area Reduced	Weld to Line	30 ±5 psig	1×10^{-7}	Difficult	Simple	Simple	Difficult	High	Poor
Continental Disc Corp.	Union Type Burst Disc	1	Aluminum Gasket	Weld	"O" Ring Plastic	None	Elastomer "O" Ring	Protective Cap	Obstructed By Diaphragm Flow Area Reduced	Weld to Line	100 ±5 psig	1×10^{-7}	Simple	Simple	Simple	Difficult	Low	Poor
Cryenco	Burst Disc Seal-Off Valve	1	"O" Ring Buna-N	---	Aluminum Cap "O" Ring	None	Elastomer "O" Ring	Protective Cap	Flow Area Unobstructed	Weld to Line	20 ±5 psig	1×10^{-8}	Simple	Simple	Simple		High	Poor
Cryolab	Burst Disc	1	---	Weld	"O" Ring Plastic	Yes	Welded	Protective Cap	Flow Area Unobstructed	Weld to Line	30 ±5 psig	1×10^{-10}	Complex	Complex	Complex	Difficult	High	Poor
C.V.I.	Relief Seal-Off Valve	1	"O" Ring Viton A	"O" Ring Viton A	Anodized Aluminum "O" Ring	Yes	Elastomer "O" Ring	Protective Cap Dissimilar Metals	Obstructed By Spring Mechanism	Weld to Line	20 ±5 psig	1×10^{-10}	Difficult	Simple	Simple	Difficult	Low	Poor
Fike Metal Products	Union Type Burst Disc	1	Copper Gasket	Weld	"O" Ring Plastic	None	Copper Gasket	Protective Cap Coated Disc	Obstructed By Diaphragm Flow Area Reduced	Weld to Line	30 ±5 psig	1×10^{-7}	Simple	Simple	Simple	Simple	Low	Good
Parker Aircraft Company	Belleville Spring Burst Disc Relief	1	"O" Ring	Weld	Plastic	Yes	Elastomer "O" Ring	Protective Cap	Flow Area Unobstructed	Weld to Line	30 ±5 psig	1×10^{-7}	Complex	Complex	Complex	Complex	High	Poor
Whitakker Corporation	Flat Disc	1	Stainless Steel Disc Diaphragm	---	None	None	Stainless Steel Gasket	Protective Cap	Obstructed By Sheared Diaphragm	Weld to Line	30 ±5 psig	1×10^{-10}	Simple	Simple	Simple		Low	Poor

COMPARATIVE ANALYSIS — BURST DISC

during the product review, have aided in establishing the reliability of the state-of-the-art hardware. The most salient features of a burst disc design have been evaluated and compared. As a result of this and other interrelated evaluations including reliability, analysis and design, has evolved the hardware that is recommended to meet Phase I study objectives.

1.1.2.3 Summary of Vendor Product Evaluation

Of the vendors' product evaluated, only two appeared to have the interest in the burst disc study to incorporate study objectives into reliable hardware. These two companies are the AMETEK/Calmec Company and Fike Metal Products. The Continental Disc Corporation and Black, Sivalls and Bryson will be solicited for the reverse buckling shear cutter type disc prior to testing of Phase II hardware.

A. AMETEK/Calmec's design provides the design through development to provide the reliability goals established for this hardware and maintains the simplicity required to make field maintenance possible. The Calmec Engineering staff has added confidence in the hardware proposed by several of the design changes and elements that they have emphasized as critical to the reliability of this hardware. Field maintenance for burst disc replacement is one of the basic requirements of the Phase I study, and this hardware will provide the capability for an increase in reliability and several improvements in the state-of-the-art. (See Figures 11 and 12)

B. Fike Metal Products was the first to propose the reverse buckling disc for this program. (See Figures 13 , 14 and 15) Their design provided all of the essential elements of the objectives required to increase hardware reliability. Their position in the burst disc industry is well established by having provided quality hardware for a variety of government users.

C. The Consolidated Precision Corporation was eliminated from consideration because they were non-responsive to the design improvements to their present hardware that were requested to meet study objectives.

D. The Parker Aircraft Company was eliminated by virtue of the complexity of their design. (See Figure 16) The design consisted of a complicated burst disc/relief mechanism. The burst portion was actuated by the pressurization of the internal area of a bellows with reseating of the poppet effected by a spring. The Parker unit incorporated the Belleville spring concept and required an extremely high cost for development with a high unit cost.

E. The Whittaker Corporation was eliminated because of a non-tamperproof design. Current problems in the field require that the thin disc diaphragm be protected from external damage.

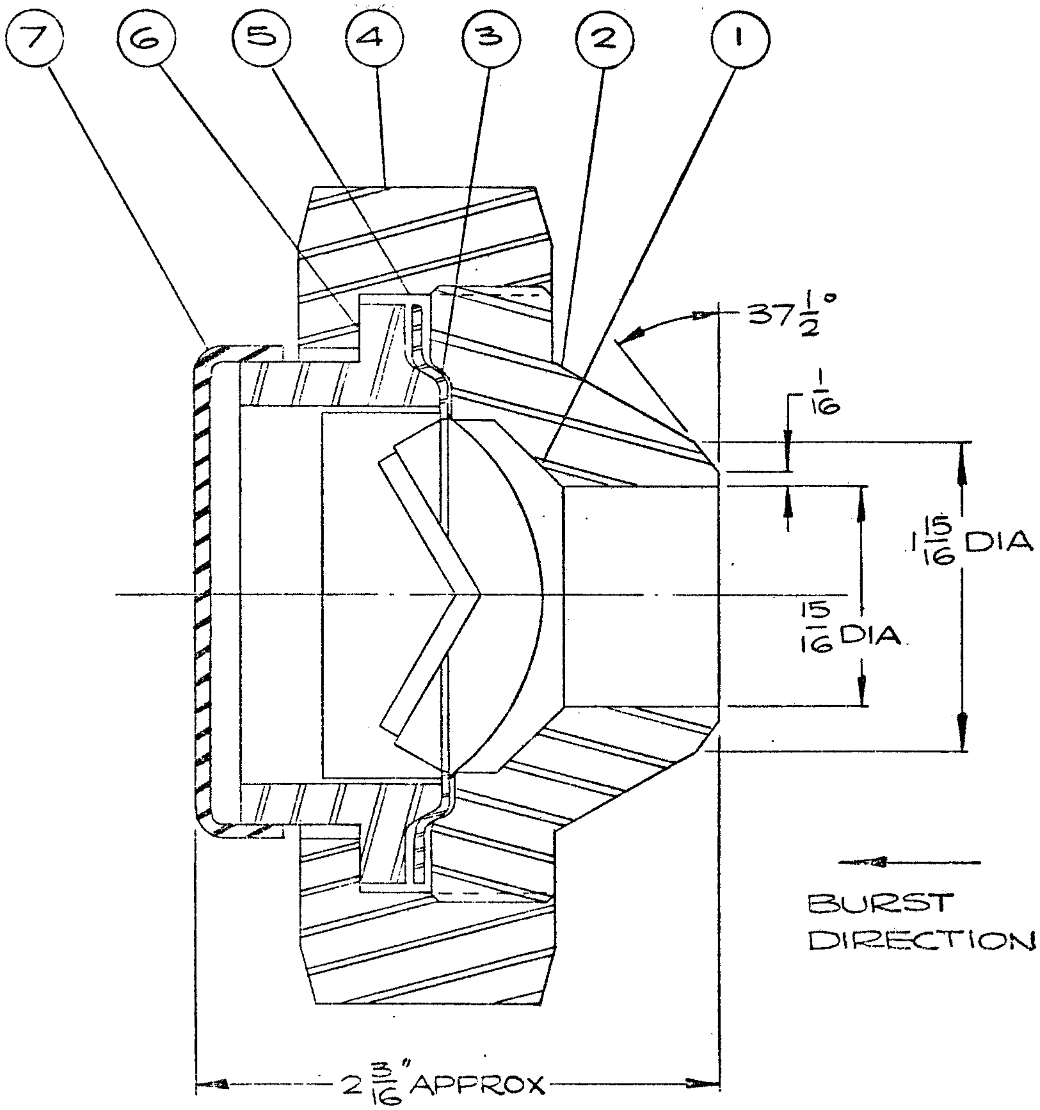
The Whittaker design incorporated a screw for perforating the disc diaphragm at a set pressure. The adjustable nature of this screw made this design very undesirable. The main seal between body and upper assembly was effected by the thin disc diaphragm itself, which would require handling of the disc seal material during maintenance.

F. The C.V.I. Company was eliminated basically because of the relief seal-off valve combination concept which was originally considered unreliable due to the externally introduced operator that was independant of the valve. This company also was not interested in incorporating any new concepts that AMETEK/Straza considered imperative to an increased hardware reliability. Their main interest was in an off-the-shelf item without the needed improvements.

G. Cryolab Company burst disc was eliminated because of a complex combination burst disc seal-off valve thermocouple station. As a burst disc, it did not have capability for a replaceable diaphragm in the field. Reliability was lowered considerably by the multi-opening assembly.

H. Cryenco was eliminated from consideration because of the disinterest in the program to incorporate design changes that would improve their hardware for use in the NASA study. Reliability was low in the existing unit due to the shaft type "O" Ring seal for the relief plug. Pumpdown operations which require the removal and insertion of this plug create wear on the seal from corrosion residue, decreasing its reliability.

I. Black, Sivalls and Bryson submitted an exceptional design for an all welded and replaceable assembly (See Figures 17 and 18). The internally threaded hold-down assembly eliminates the large diameter created by the use of a hex nut. High unit costs made this design uneconomical for testing.



INDEX NO	PART NO.	NO. REQ	DESCRIPTION	MATERIAL
7		1	DUST COVER	POLYPROPYLENE
6		1	RETAINER	304 SST
5		1	BLADE & SEAT ASSY	17-4 PH
4		1	NUT	303 SST
3		1	SEAL	COPPER
2		1	BASE	304 SST
1		1	RUPTURE DISC	

CALMEC AMETEK RUPTURE DISC ASSY

Figure 11. Reverse Buckling Rupture Disc

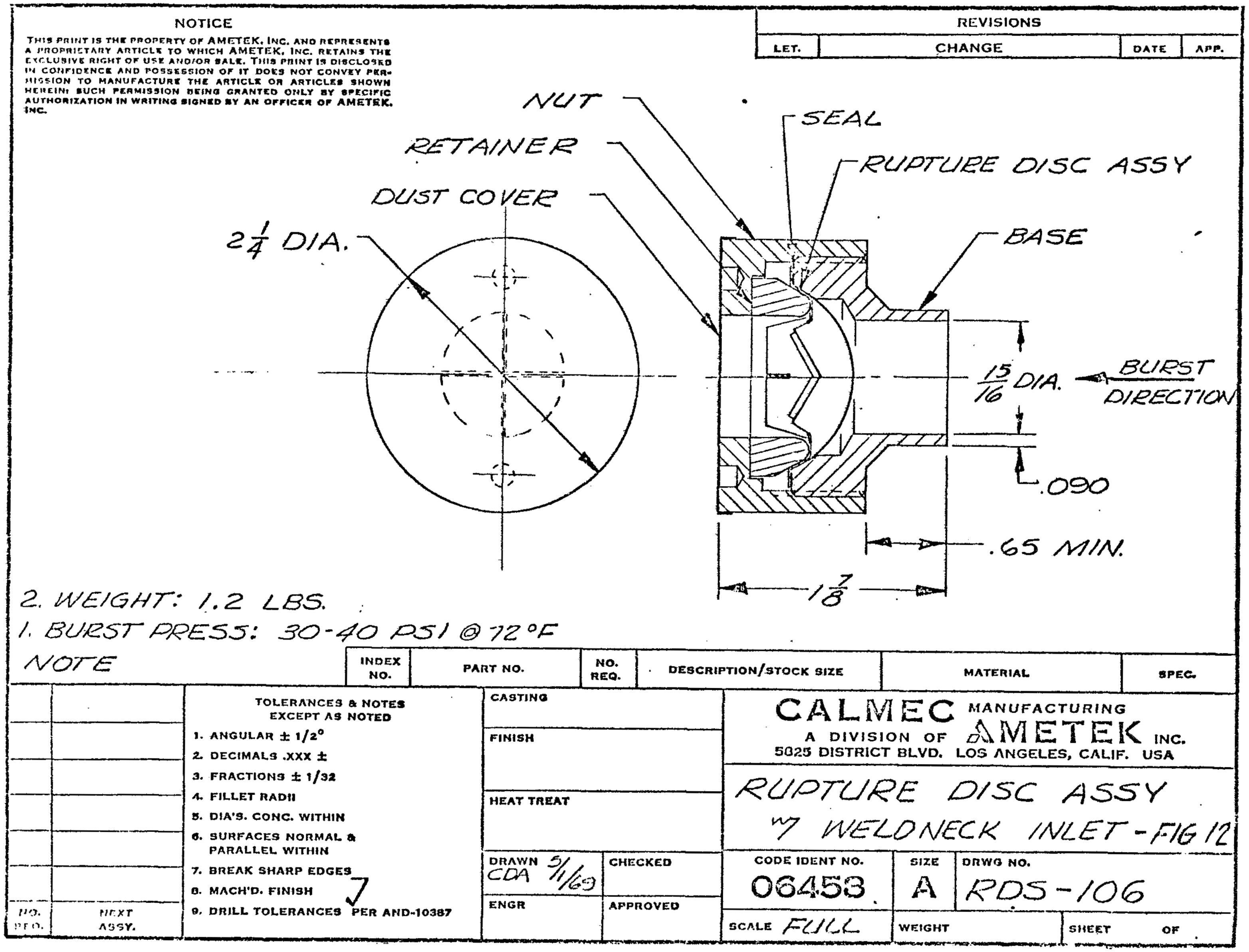


Figure 12. AMETEK/Calmec Reverse Buckling Rupture Disc, Weld Neck

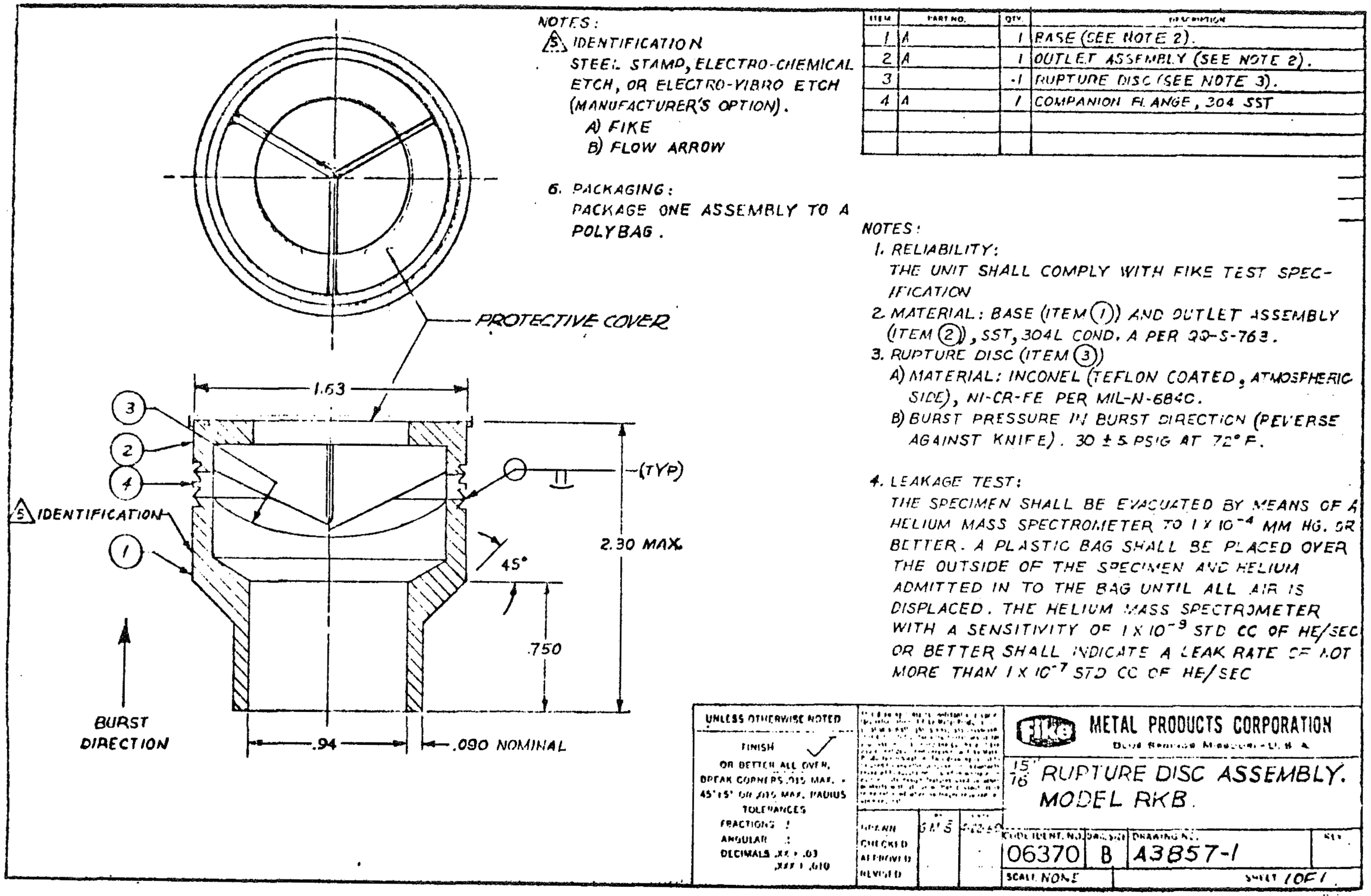


Figure 13. Fike Rupture Disc (All Welded)

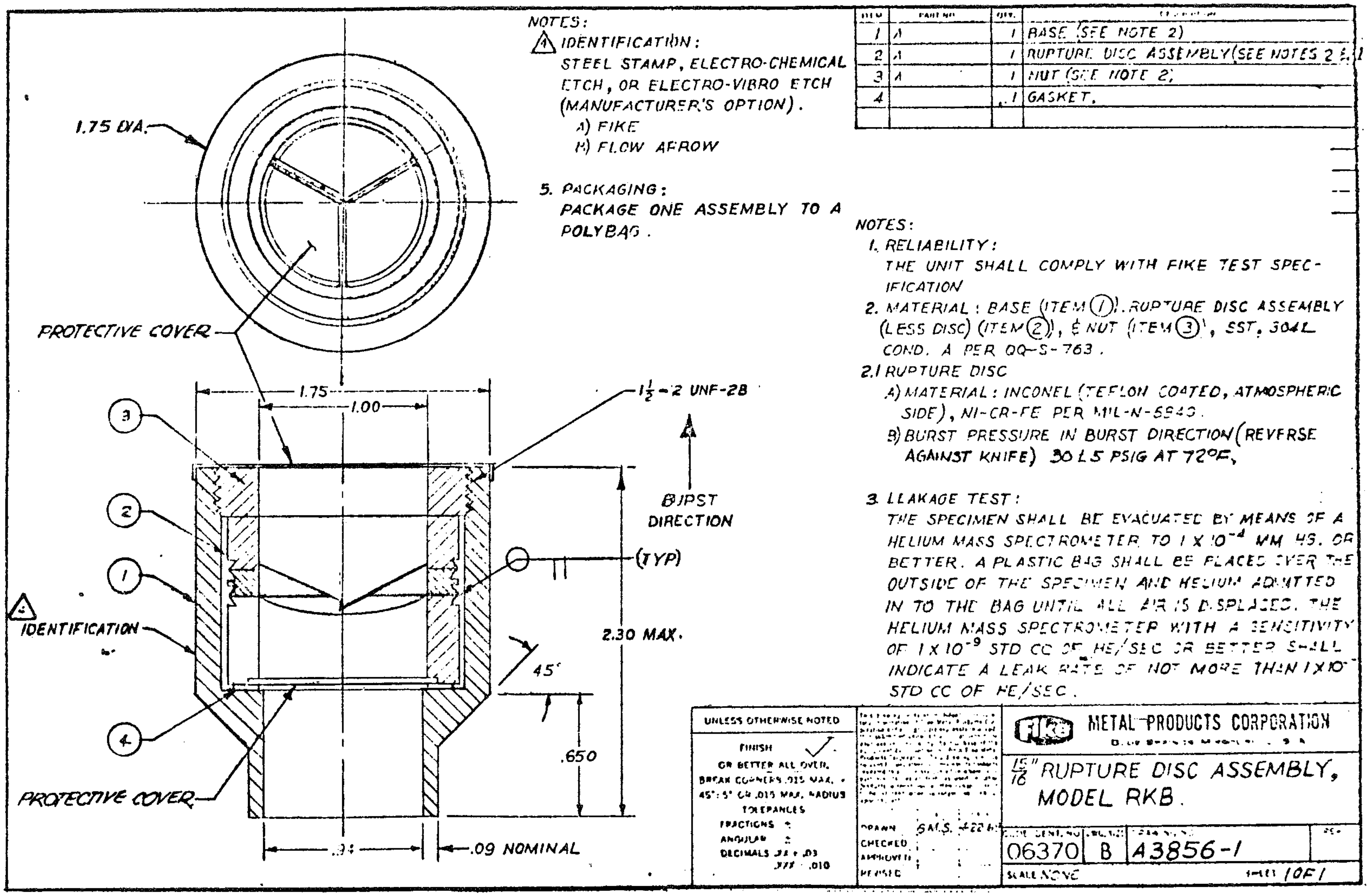
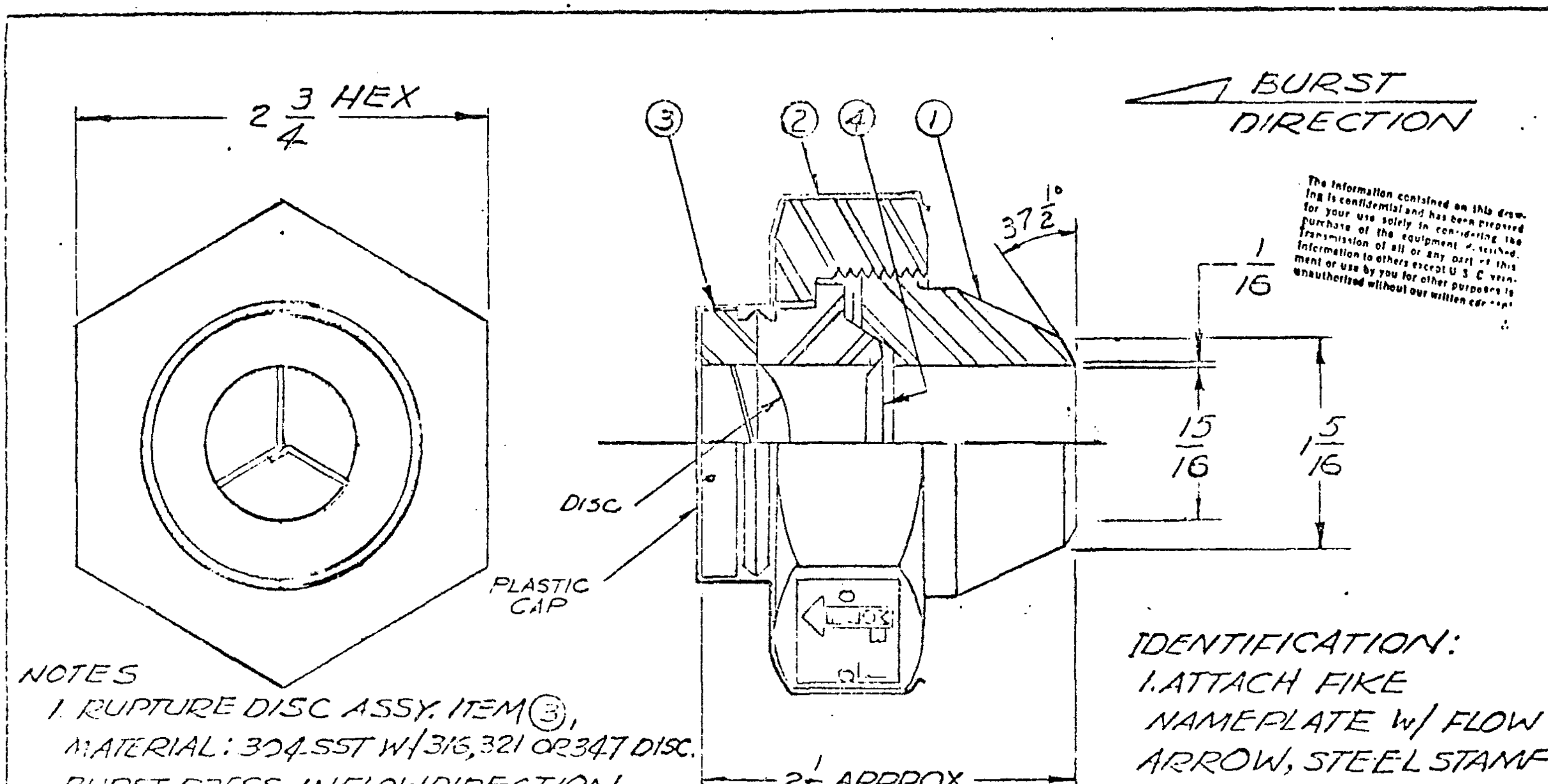


Figure 14. Fike Rupture Disc (Replaceable)



NOTES
1. RUPTURE DISC ASSY. ITEM ③, MATERIAL: 304 SST W/316, 321 OR 347 DISC. BURST PRESS. IN FLOW DIRECTION 30 ± 3 PSIG @72°F
2. LEAKAGE: LEAK RATE TO BE LESS THAN 1x10⁻⁹ CC ATM. CC/SEC. HELIUM.

IDENTIFICATION:
1. ATTACH FIKE NAMEPLATE W/ FLOW ARROW, STEEL STAMP OR ETCH,
a) A 3790-1 RKB
b) 304 SST

PRELIMINARY

ITEM	PART NO.	QTY	DESCRIPTION
1	130FU-1	1	BASE, 304 SST
2	130NU	1	NUT, 303 SST
3	A3790-90	1	RUPTURE DISC ASSEMBLY
			SEE NOTES 1 & 2
4		1	GASKET ALUM. 1100-0
			.010 ± .002 THICK
			(OR COPPER)

FIKE METAL PRODUCTS CORP.
BLUE SPRINGS, MISSOURI
NOV. 1 2 1968

SCALE	APPROVED BY	CODE IDENT. NO.	DRAWN BY
FULL	VLL	06370	MBD
DATE: 11-11-68			REVISED

1" UNION TYPE, RKB W/ WELDNECK INLET, FREE OUTLET

FIGURE 15

DWG SIZE: A | DRAWING NUMBER: A3790-1 | REV.

Figure 15. Fike Union Type Rupture Disc

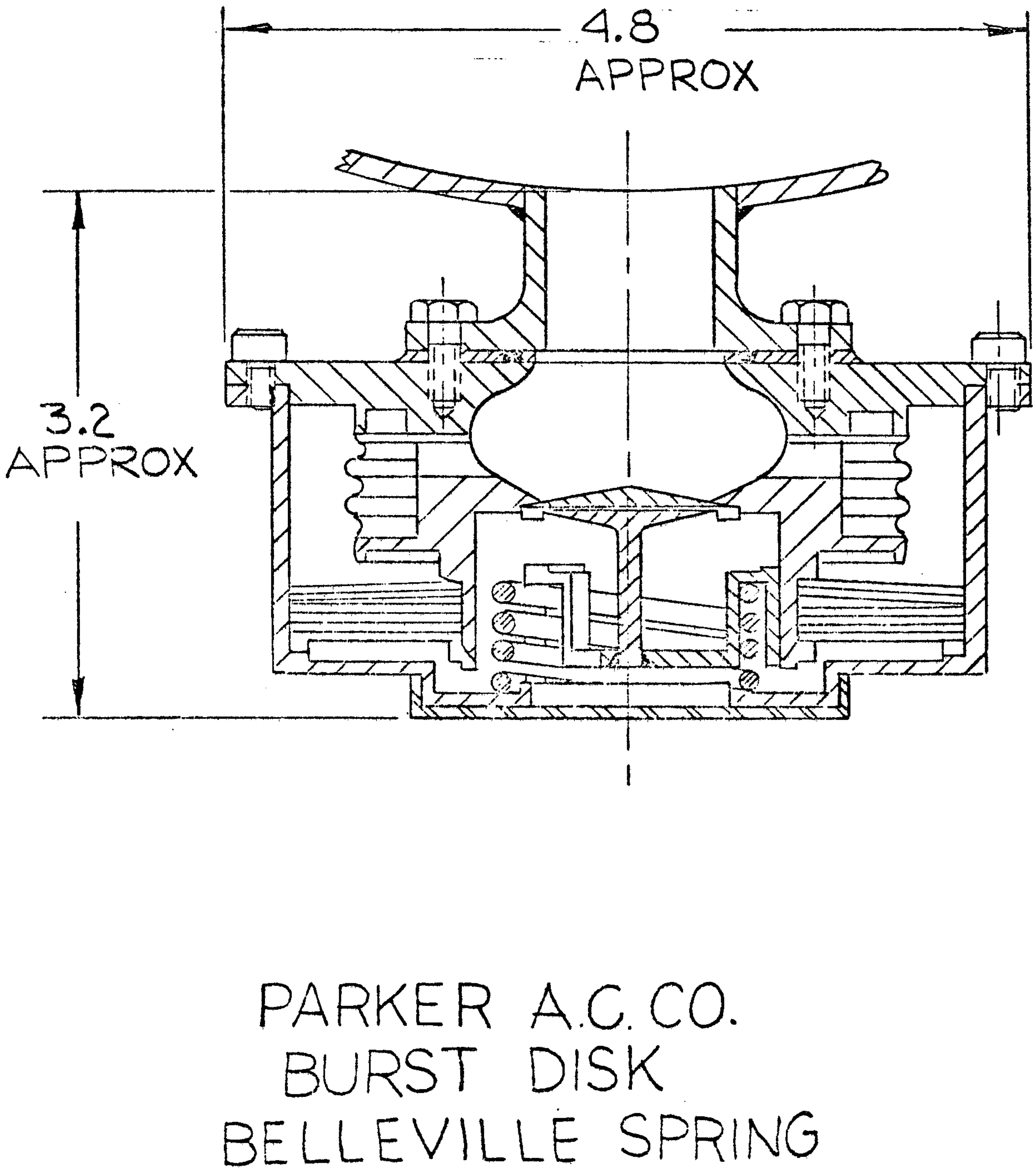


Figure 16. Parker Aircraft Rupture Disc

BLACK, SIVALLS & BRYSON, INC.

ENGINEERING DATA

Description - 1" - 150 lb. Max SPL Prepared By M. Free No. A

WELDED TYPE R.B. 90 Checked By ________ Date 4-7-69

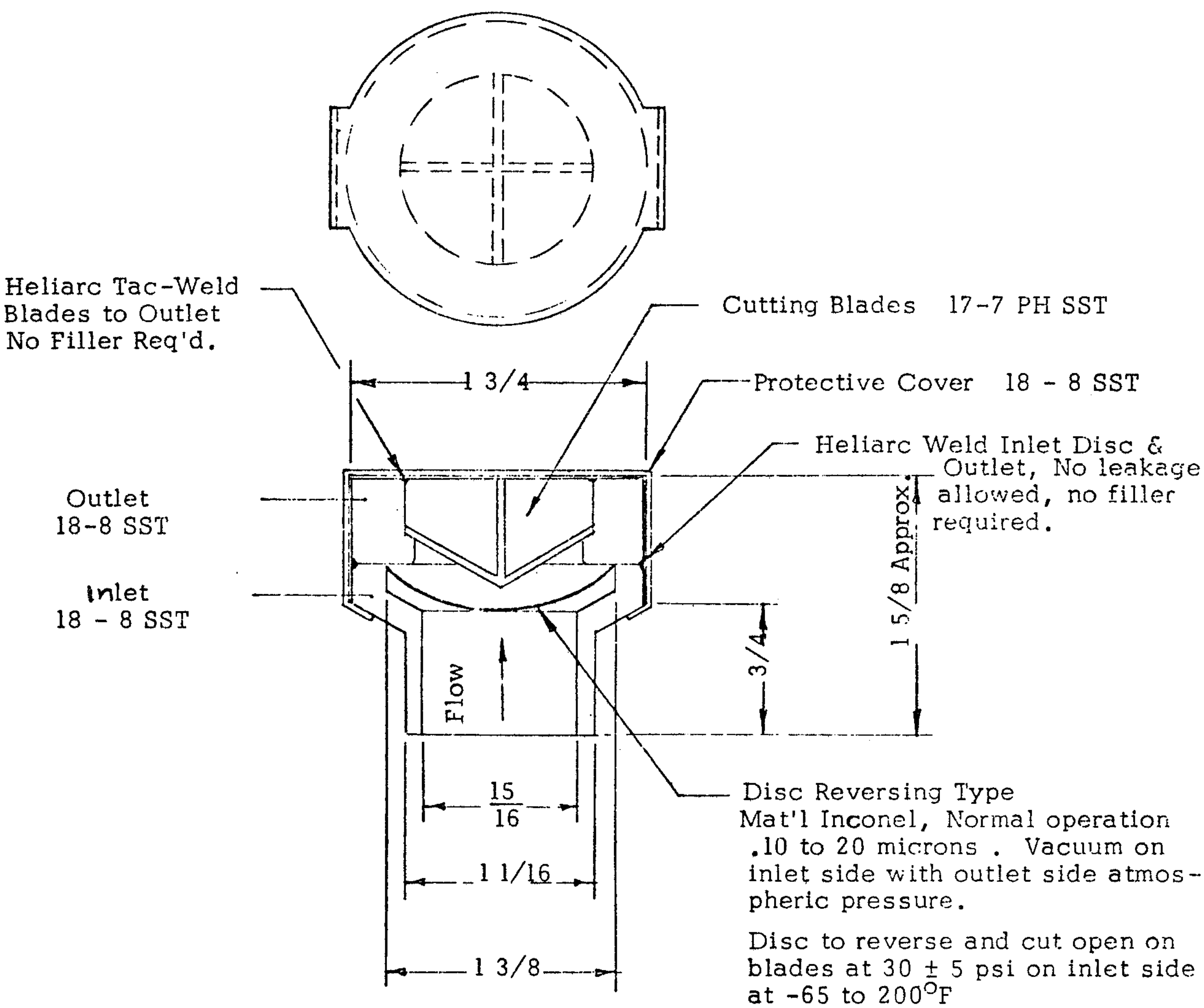


Figure 17. BS & B Reverse Buckling Rupture Disc, All Welded

BLACK, SIVALLS & BRYSON, INC
ENGINEERING DATA

Description 1" 150 lb. Max SPL   Prepared By M. Free No. B

SCREW TYPE R. B. 90   Checked by   Date 4-8-69

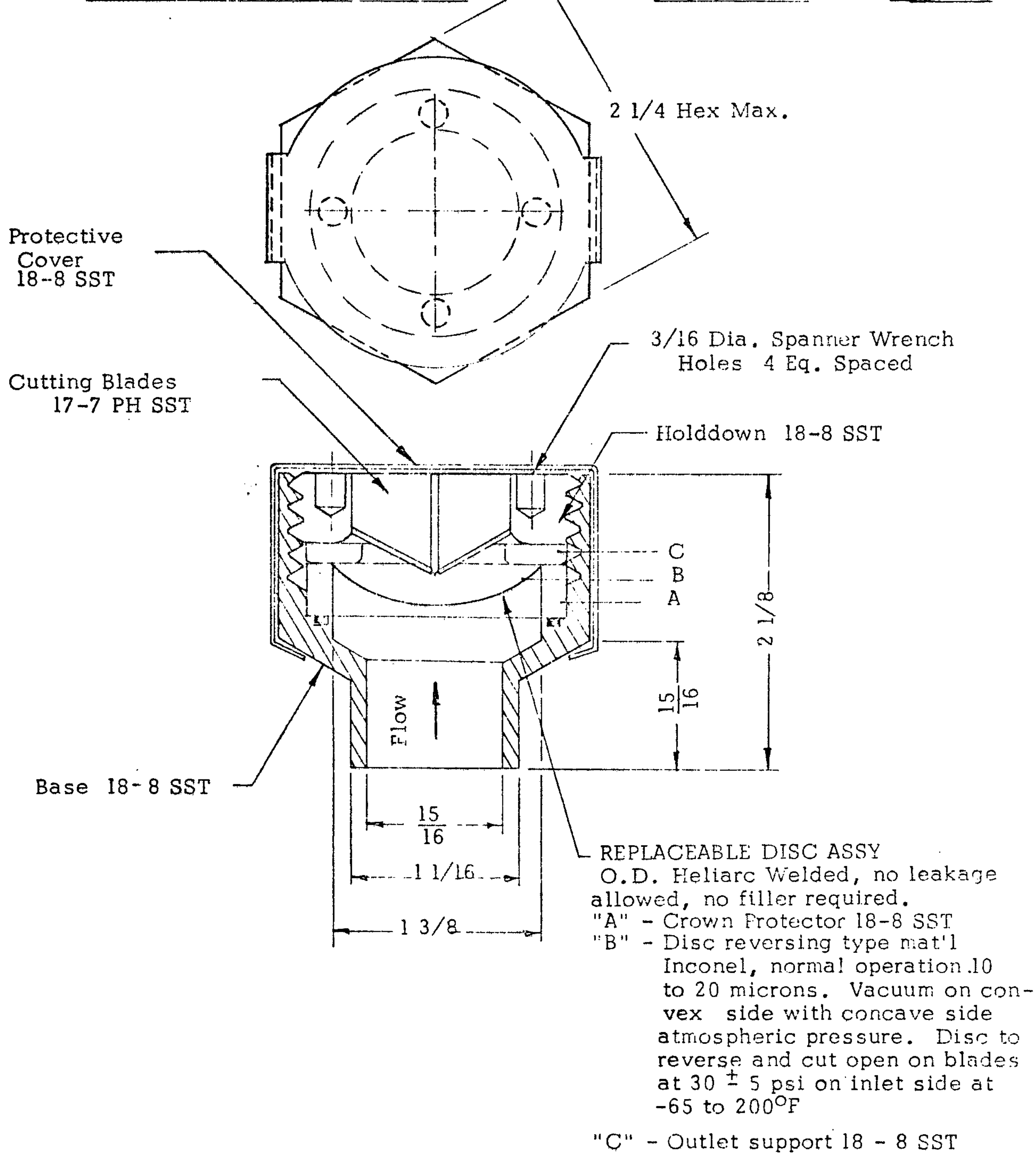
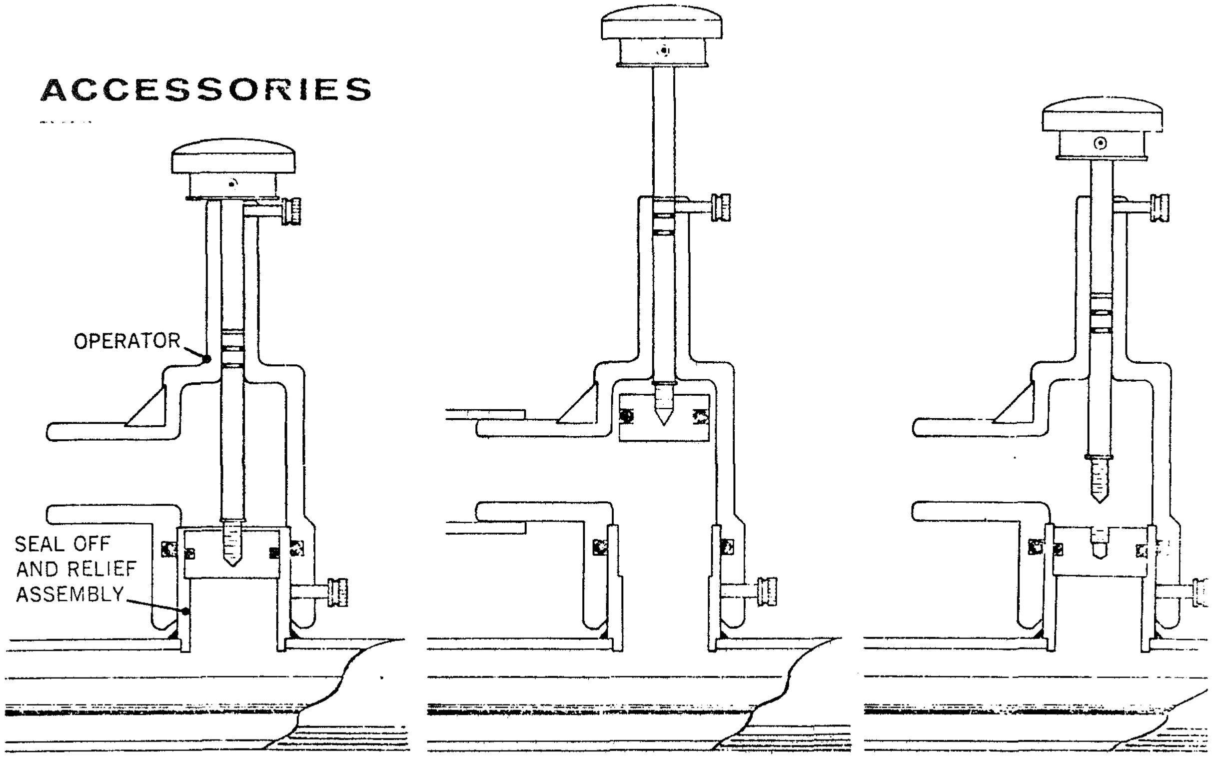


Figure 18. BS & B Reverse Buckling Rupture Disc, Replaceable Disc

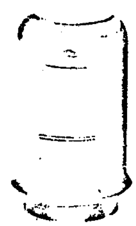
ACCESSORIES

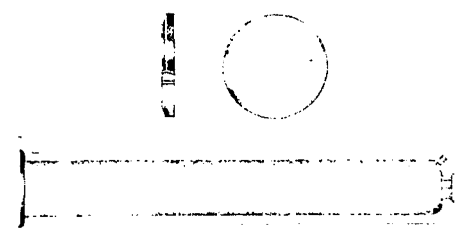


PUMP OUT

① Operator in place prior to evacuation ② Seal off cylinder withdrawn during evacuation ③ Seal off cylinder in place af evacuation

VACUUM SEAL OFF AND RELIEF ASSEMBLY		
PART NO.	SIZE	PRICE
B8331	½″	23.50
A4950	1⅛″	37.50



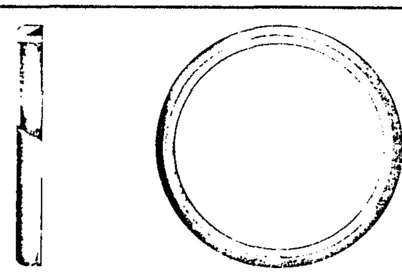


BAYONET DUST COVERS

To order either male or female dust covers, specify ma female bayonet part number followed by – DC.

PRICES ON REQUEST

VACUUM PUMP OUT OPERATOR		
PART NO.	SIZE	PRICE
B4715	½″	47.50
B4946	1⅛″	62.50



BAYONET NOSE SEALS

To order specify male bayonet part number followed by

PRICES ON REQUEST

CRYENCO
Cryogenic Engineering Co.
4955 Bannock St.
Denver, Colorado

Figure 19. Cryenco Seal-off/Relief Assembly

1.1.3 DESIGN PHASE

The objectives for the Design Phase of the Study Program were to perform the following basic tasks:

A. Develop the necessary improvements in burst disc design and provide installation procedures that will correct field problems resulting from corrosion, contamination, and structural damage.

B. Analyze the problems associated with burst discs and their installation with particular attention to sealing after disc replacement.

1.1.3.1 Design Criteria

Upon completion of the hardware evaluation, the design criteria for burst discs was formulated. This Phase I design criteria included:

A. Establishing the disc burst pressure to within the range of previous requirements (25^{+25}_{-0} psi). An evaluation of the inner line structural integrity placed 50 psig as the maximum pressure allowable. With a high tolerance in burst pressure, a coated disc for corrosion protection was made possible.

B. Flow requirement for the burst disc is 350 scfm.

C. The burst disc shall be compatible with launch environment experienced at Complex 39, Kennedy Space Center for a minimum period of five years.

D. Proof pressure of the body is 150 psig.

E. Maximum leakage allowable 1×10^{-7} STD cc GHe/sec while maintained at 1 atmospheric external and evacuated to one micron internal.

F. The unit operating temperature shall be from plus 200 to minus 65°F.

1.1.3.2 Design Objectives

The burst disc program design objectives were developed to assure that no area in burst disc design would be overlooked that would ultimately affect part reliability. Proposed hardware will be designed to include the following objectives:

A. Improved seals and seal seating design;

B. A reduction or elimination of the potential for contamination during installation and maintenance operations;

C. Corrosion resistance from salt fog environment;

D. Seal from external contamination such as sand and dust;

E. Low profile stainless steel body to reduce impact damage;

F. The unit shall be of such a design that technicians unfamiliar with vacuum equipment can perform maintenance.

G. Seal leakage potential due to contamination of "O" rings will be reduced.

Component Design Review

Each component reviewed has been done so with the intention of improving the critical areas of the design in the following areas:

A. Sealing surfaces;

B. Seal materials;

C. Disc (diaphragm) materials;

D. Lubricants;

E. Sealants;

F. Corrosion resistance;

G. Vacuum support (if required).

The pneumatic design requirements were anlyzed to determine the optimum of worst case conditions relative to:

A. Fluid medium;

B. Annular space;

C. Flow area required compatible with maximum flow.

The structural design requirements were also analyzed to establish the optimum in:

A. Materials;

B. Shock and vibration stability;

C. Welding and assembly;

D. Replaceability of seals and discs.

1.1.3.3 Analysis

In order to support development designs, it was necessary to establish minimum flow requirements that could be used in the development of hardware. The main areas of concern for a preliminary design were:

A. Establish the maximum size of line failure (crack in the weld resulting from inclusion, porosity, or gas hole) based on failure history for welds;

B. Establish the maximum volume of fluid that would enter the vacuum annulus creating the over-pressurization condition.

C. Establish the volume of gas boil-off that the burst disc would be required to flow in the event of a line failure (and establish which cryogen would result in the highest boil-off rate).

D. Establish the pressurization of the annular space resulting from an external line failure.

The analysis (See Appendix) established the requirements for the initial design development performed at AMETEK/Straza and hardware manufacturers. The manufacturing and welding failure history at Straza was reviewed to establish the maximum possible fatigue crack, weld crack, or weld porosity that could occur in a vacuum jacketed cryogenic line. The size of failure was established as .010 inch by 1.0 inch long for a maximum .010 square inches.

The analysis indicated that a one-half inch diameter burst disc would provide a safety factor of 5.0 in handling flow created by a failure from a .010 inch hole if the failure occurred on the inner line.

The following investigation determined that the effective size of the burst disc assembly should be one inch to safely discharge accumulated air from the annulus of a leaking outer vacuum jacketed line. The most reasonable assumption for leakage into the annulus will be based on a hole .010 square inches in area in the vacuum jacket of a liquid hydrogen line.

The liquid hydrogen inner line will be covered with at least ten layers of radiation shielding. These are radiation insulators that provide thermal resistance to heat flux input into the LH_2 line. They also serve to reduce the heat flux into the annulus during the warm gas purge which follows propellant loading operations.

Test results published by the National Research Corporation indicated a temperature of approximately 540^{o}F on the external layer of their insulation in a vacuum of 10^{-4} mm of Hg for liquid nitrogen. When the vacuum is broken by the inrush of air through a vacuum jacket opening, some of the air will penetrate the insulation, thus increasing its thermal conductivity. The remainder of the air in the annulus will also increase the overall thermal conductivity, with the end result being a drop in temperature of the insulation and the vacuum jacket.

The continuous heat flux input will drive the molecules of air with the higher energy levels to the circular inner line where they will condense and run off as a liquid and slush.

This liquid and slush, when dropping off the inner line, will impinge on the relatively hot vacuum jacket and vaporize in the same manner that water droplets will vaporize on the surface of a hot stove. The air will continue recycling from gas to liquid and slush for the entire period of transfer time. In some cases where the annular space is less than one inch, it may be possible to fill the annulus with slush. Following the LH_2 transfer, rapid warmup of the line occurs by continued heat input to the outer jacket and inner line from a warm purge. This added heat causes a rapid pressure buildup in the annulus. The rate of the pressure increase establishes the venting capacity requirement for the line annulus. The analysis (See Appendix Item b, 1, 2, & 3) shows this minimum flow orifice required to flow the generated gas is one inch in diameter.

This orifice will flow 6.50 ft^3/ sec initially, then decay to zero ft^3/sec in 6.22 minutes, approximately at sonic velocity at a $\frac{\Delta P}{P} \sim .5$. After 6.22 minutes, the total flow capability would be 2,426 ft^3.

An analysis was also made to determine the size of burst disc for various line sizes ranging from one inch inner line and two and one-half inch outer line to 22-inch inner line and 24-inch outer line.

The results of this analysis indicates that a one-inch diameter burst disc is adequate to safely relieve the annulus pressure of any LH_2 line size from 1" X 2 1/1" to 22" X 24" and 20 feet long.

Application

1.1.3.4 Sealing Methods, Materials and Usage

Metal Sealing for Burst Disc

The degree to which the seal is affected on the burst disc design is accomplished by making one of the surfaces relatively soft and compliant so that it readily conforms to the harder surface irregularities.

Sufficient sealing load is also required to plastically deform the softer of the two sealing surfaces. By carefully finishing the mating surfaces, good sealing can also be achieved with reduced sealing loads. Resiliency of the metal seal for this application is of little concern within the study operating temperature parameters.

Besides the basic consideration of the seal material properties and interface conditions, seal load is to be considered if the stringent leakage requirements are to be met.

In general, the better the finish of the mating surfaces, the lower the stress required for achieving a good seal.

Surface Finish for Metal to Metal Seal

Surface topography determines the degree of interface sealing. Data is available which shows the typical application of surface roughness values which may be obtained by various manufacturing methods. As a general rule, metal seals require 4 to 16 micro-inches, depending primarily on lay.

Metal to Metal Compression Sealing

Plastic deformation plays an important role in metal to metal sealing. Five separate conditions of material flow are experienced:

A. Initial contact between two surfaces having some asperity results in plastic deformation at some high asperities under low apparent seal stress. There is little overall increase in actual contact area over the unloaded condition. This loading is inadequate to accomplish sealing.

B. As the load increases, the asperities of average height come into contact and deform plastically. A rapid increase in actual contact area with nominal increases in normal stress is experienced. Leakage in this condition decreases with stress more rapidly than in condition (A). At the end of condition (B), the apparent seal stress is near the yield strength of the weaker material.

C. Plastic flow of the asperities continues, and pile-up of material between asperities begins. Strain hardening and bulk flow of the softer material begins during this condition.

D. Bulk flow of the seal material increases the actual contact area by shearing along the surface and by physically increasing the apparent area of contact. The amount of bulk is dictated to a large degree by the actual seal stress hardenability of the seal material.

E. The normal stress begins to cause bulk flow of the harder material. This condition should be avoided if it is intended that the joint be opened and then released.

Although dependent on surface finish, mating of metal to metal surface generally requires a sealing stress of two to three times the yield strength of the softer material.

Metal to Metal Sealing by Shear Deformation

The yielding necessary for the production of seal between two material surfaces is not caused by a high compressive stress alone, but by a combination of stresses existing in the material to be deformed. Stress can be applied in a manner that causes the soft material to strain in shear, thereby requiring less load to achieve a plastic stress condition at the sealing interface. Knife edges, shear "O" Rings, and other geometrics which cause high stress concentration factors can be used to accomplish this.

Materials Properties for Seals

Any solid material can potentially be used as a seal; however, the ideal seal material should have the following properties:

A. Capability of storing elastic energy to allow the seal to maintain interface loads under conditions of resiliency or low elastic modulus.

B. Capability of containing high differential pressures without deformation (high yield strength).

C. Capability of deforming and conforming to minute surface asperities (soft).

D. Resistance to damage during handling or operation such as nicks, cuts, scratches (hard).

E. Resistance to creep or stress relaxation as a result of applied load or elevated temperatures (stable and inert).

F. Easy to fabricate (low cost).

G. Capacity for unlimited re-use.

H. Chemical compatibility with the sealed media.

I. Resistance to fluid flow through the seal body (low porosity or low permeability).

Obviously, no single material will meet all of the above requirements. Selection of the metal seal for study hardware has been based on the best combination of properties for the study application.

In metallic seals, plastic flow of one of the materials at the interface is usually required to obtain an effective seal. Softer materials with a desirable high plastic strain range will usually have a low ultimate strength level. To balance the requirements of high strength in the seal body and good plastic flow under low stress at the interface, hign strength materials are often plated with a thin coating of a softer material. Plating materials and their applications are shown on Table 2.

Table 2. Platings and Coatings

PLATINGS AND COATINGS

Standard Platings and Coatings for Metallic Seals

(Adapted from "Metal V-Seal," Cat. 8800, 1964, Parker Seal Company, Culver City, California)

Plating or Coating	Temperature Range (°F)	General Recommendations
Silver	- 325 to + 1650	Excellent general purpose plating for high temperature resistance, but generally less suitable for cryogenic temperatures than gold or Teflon. Excellent chemical and radiation resistance.
Gold	- 423 to + 1850	Similar to silver but somewhat better resistance to certain corrosive fluids. Improved high and low temperature resistance but higher in cost than silver.
Teflon (TFE)	- 423 to + 500	Excellent coating for applications up to + 500°F. Excellent chemical resistance. Particularly suitable for cryogenic applications.
Teflon (FEP)	- 423 to + 400	Similar to Teflon (TFE) but somewhat softer and more dense. High temperature resistance lower than Teflon (TFE).
Kel-F	- 423 to + 300	Similar to Teflon, but more resilient and plastic at low temperatures, and generally higher in cost than Teflon.
Platinum	- 423 to + 3100	Highest temperature-resistant plating. Normally limited to use with ultra high temperature base metals such as TZM.
Nickel (soft)	- 325 to + 2500	High temperature-resistant plating but slight sacrifice in softness and ductility compared to other platings.
Lead	- 65 to + 450	Very soft plating but limited temperature resistance. Excellent radiation resistance.
Indium	- 320 to + 300	Very soft plating but limited temperature resistance. Suitable for cryogenic applications.
Aluminum	- 423 to + 900	Compatible with most oxidizers and fuels, but extremely costly as a plating material. Particularly suitable for liquid and gaseous fluorine.
Tin (pure)	- 32 to + 350	Very ductile, but limited temperature resistance. Usage limited to a few corrosive chemicals.
Copper	- 423 to + 1900	Suitable for vacuum applications; resistant to fluorine and certain other corrosive chemicals.

Seal Re-Usability

The degree to which seal components may be re-used after disassembly is an economic consideration, particularly for separable connector applications. In general, when plastic deformation of one or both of the components is required to effect a seal, the component will not be re-usable; if the deformation is in the elastic range, the components will probably be re-usable. In those areas where plastic deformation is required, consideration should be given in material selection to limiting the plastic deformation to one component only.

1.1.3.5 Burst Disc Reliability Program

A complete functional on-site review of Launch Complex 39 and other Kennedy Space Center installations was accomplished early in the program to gather the maximum amount of available reliability information on present burst discs.

The Kennedy Space Center Data Bank and Failure Reporting Systems were fully interrogated for all available data. Tab runs were made from the data bank and examined in detail. Kennedy Space Center and Boeing Reliability personnel were extensively interviewed.

Straza internal failure data for burst discs was tabulated and reviewed. A substantial effort was exerted to identify and calculate the degree of severity of each of the predominant failure modes for each of the items.

Subsequent to a comprehensive review of the preceding information, a basic decision was made concerning the reliability calculations to be accomplished for burst discs.

The exponential distribution normally used as characteristic of systems with many parts whose failures will average out to essentially a random failure occurrence is not the reliability frequency distribution which best describes the characteristics of the items under study. The "normal" probability distribution is a better description of the reliability characteristics of the individual items. Units following a normal distribution have a failure rate that increases with time; essentially a "wear-out" characteristic due either to functional use, cycling effects, or effects of the environment such as corrosion. The individual item reliability, therefore, is equated to the probability of survival (without failure) of the item for the two-year period. Where:

$$R = \frac{\text{Number of units which did not fail}}{\text{Total number of units in use}}$$

The probability of survival ratio utilized is the least complex of reliability calculations, but was necessitated basically by the absence of substantial time-oriented data.

It was determined that heavy reliance would be placed on establishing critical failure modes and utilizing the reliability (probability of survival) numbers as a measure of the severity of each failure mode. It was recognized that the minimal data and differences of environmental and other factors mixed in the data was likely to introduce an uncertainty into the reliability numbers. But, by using the same approach for each of the subsequent calculations and evaluations, it would be possible to establish the relative degree of improvement or degradation from that established base line. The relative measure of improvement was determined to be the primary quantity required by the study, rather than a fixed true reliability number for a long operation period with a high confidence factor. That figure is not available with the data recorded.

Engineering Reliability supported the Phase I study of burst discs using a four-step approach to the problem. The methodology utilized was intended to provide the maximum visibility of the over-all system situation to the individual detailed design problems. The following four reliability milestones were used:

A. Document actual existing hardware reliability.

B. Establish preliminary reliability goal.

C. Establish present state-of-the-art reliability.

D. Establish final reliability goal.

Existing Hardware Reliability

The comprehensive review mentioned previously was performed in conjunction with the design engineer to establish what the operational requirements demand of the various components versus what is the inherent capability of the equipment to satisfy that demand.

All failure data, repair data, maintenance data, unsatisfactory condition or procedure data, and all operating environment data made available by the Contracting Agency was reviewed and a detailed examination or analysis made as to the cause and effect of each incident. Each component deficiency was categorized and a determination made of the relative contribution of this type of deficiency to the total performance of the component.

By the systematic grouping of faults and the establishment of the degree of effect on performance of each category of fault, visibility was provided to direct attention to areas of greatest need and greatest potential for improvement.

The existing hardware reliability value and the calculations from which it was derived were documented and the derived value was cross-checked with available in-house data on the same type components (See Table 3).

Preliminary Reliability Goal

The preliminary reliability goal was established using the existing hardware reliability values. The insight developed in analysis of existing hardware failure modes was utilized to set a preliminary goal of eliminating those modes most practical to do so or improvement in those areas of greatest impact on performance

Preliminary Reliability Goal - Burst Discs

A. Failure Potential

(1) Possibility of damage from external causes:

(a) Shock

(b) Impact

(c) Vibration

(d) Handling

One unit out of 3000 will leak as a result of (a), (b) and (c). (R = .9996)

One unit out of 3000 will be damaged to the extent that leakage will result. (R = .9996)

(2) Possibility of damage to mating surfaces, seal faces, etc., as a result of disassembly.

(a) Removal of collar, disc, "O" Ring, etc., to assembly onto line assembly will result in one unit having foreign matter added out of 3000 units. (R = .9996)

Table 3. Existing Hardware Reliability

Failure Possibilities	Approx. No. of Units	Actual No. of Failures
a) Shock	202	0
b) Impact		0
c) Vibration		0
d) Handling		0
e) Seal Damage		0
f) Seal Surface Damage		0
g) Foreign Mtl. (Sand)		0
h) "O" Ring		0
i) Lack of Lubricant		0
j) Faulty Part from Vendor		0
k) Faulty Weld @ Assy.		0
l.) Corrosion		0
m) Faulty Assy prior to Shipping		0
n) Tampering		1
o) Disc Damage		1
p) Structural Damage		1
	202	3

Existing Hardware Reliability = .9851

EXISTING HARDWARE RELIABILITY

This will result in "O" Ring damage and will require replacement of "O" Ring.

(b) Removal of disc will result in damage to the disc. This will result in disc prematurely rupturing at 15 psig (one unit out of 3000). (R = .9996)

(3) Possibility of corrosion due to atmosphere.

(a) None.

(4) Possibility of damage to internal surfaces due to foreign material being introduced into valve from annulus - None.

(5) Possibility of unit assembly will result in leakage at weld (one weld out of 3000 units). (R = .9996)

(a) Will necessitate removal of internal unit and effect weld repair.

(6) Failure due to faulty vendor parts being received at Straza prior to assembly - body porosity.

(a) 2% of 300 units = 6 units. Will not cause a serious failure, but will be discovered during system checkout. (R = .9980)

(7) Possibility that unit will not flow adequate amount of gas under catastrophic leak into annular space.

(a) None - Unit will be designed under worst condition flow capability.

(8) Possibility of "O" Ring failure due to age and incompatible lubricants.

(a) Age control will be implemented to preclude "O" Ring failure due to improper aging - fail one out of 3000 units. (R = .9996)

(b) Lubricant compatibility and exclusion of lubricant will result in two out of 3000 replacement due to leakage at "O" Ring. (R = .9993)

(9) Total failure potential from all causes sum of Items (1) through (8) above. Total reliability considering all failure modes: $R = .9953$

State-of-the-Art Reliability

A data search was instituted using customer data, vendor data, industry data, and in-house data. The reliability data services of the IDEP Program, the FARADA Program, the Defense Documentation Center (ASTIA), the NASA Information Center (PRINCE), the VSMF Design Data File, and others were utilized (See Table 4).

The accumulated data was used to define the current state-of-technology for each of the components. Emphasis was placed on the actual operating test data when available, rather than potential achievements or analytical projections. The data accumulated was correlated to the same format as the data on the existing hardware so far as possible. This provided a basis of comparison and illuminated the detailed areas where improvement potential existed.

The state-of-the-art reliability was heavily dependent on vendor information and on specific available design types.

Final Reliability Goal

The final reliability goal was established based on the final component configuration defined in the final Phase I Technical Report. It is a numeric expression of the inherent improvement in performance based on the physical change to the component.

The elimination of a failure mode or a demonstrated decrease in probability of occurrence of an unsatisfactory condition or procedure is required to justify an increase in reliability level.

Several trade-off studies/analyses were conducted in the course of the study. Evaluation from a reliability and failure modes viewpoint was made of four basic types of burst discs. A further study was made between the reverse buckling and Belleville spring type as a direct comparison.

A sequential test design for reliability was established as a guide to the design engineer in determining the number of tests, test cycles or test specimens required, and the significance of the testing as related to confidence level of the hardware projected reliability.

Table 4. **Hardware Reliability State-of-the-Art**

STATE-OF-THE-ART HARDWARE RELIABILITY ANALYSIS

Failure Mode Susceptibility	TYPE A Flat	TYPE B Prebulged	TYPE C Reverse Buckling	TYPE F Belleville Spring	R GOAL (+6 Failures)	AVG State-of-the-art Failures	State-of-the art Reliability Number
External Damage	2/3000	2/3000	2/3000	3/3000	2/3000	2.25/3000	
Disassembly Damage	2/3000	2/3000	-0-	3/3000	2/3000	1.75/3000	
Corrosion	2/3000	2/3000	2/3000	3/3000	-0-	2.25/3000	
Contamination	2/3000	2/3000	2/3000	2/3000	-0-	2/3000	
Assembly Weld Leak	1/3000	1/3000	1/3000	1/3000	1/3000	1/3000	
Inadequate Flow	-0-	-0-	1/3000	-0-	-0-	.25/3000	
"O" Ring Failure	3/3000	3/3000	-0-	3/3000	3/3000	2.25/3000	R = .9940
					Total - 14	Total - 17.75	

The final reliability goal is based on the reverse buckling type configuration with cutting blades.

It is assumed the same failure potential as indicated in the preliminary reliability goal calculation still exists, i.e., the same environmental and operational stresses, and that the basic failure modes are:

(1) Damage from external causes

- a) Shock
- b) Impact
- c) Vibration
- d) Handling

(2) Disassembly damage

- a) Assembly to line
- b) Disc replacement

(3) Corrosion

(4) Contamination

(5) Weld leakage

(6) Inadequate flow

(7) Seal failure

Based on the latest configuration and assuming substantiation during test phase, the basic failure modes have been modified or eliminated as follows:

(1) External damage

- a) Shock - none (same as before)
- b) Impact - one (1) of 3000 as stated in preliminary review (still possible)
- c) Vibration - none (same as before)

1.1.4 Phase II Proposal

1.1.4.1 Test Plan

The Phase II Test Plan (including the hardware procurement) is submitted with the Phase I Technical Report to reflect the technology gained through the Phase I task and express the philosophy for the remainder of the Vacuum Jacketed Lines Technology Advancement Program. The Phase II plan is the result of the study activity that has been conducted during Phase I as the program has evolved through the various stages of development including: Hardware Evaluation, Product Review, Reliability and Design Phases.

In summary, the conclusions and recommendations that are presented in this Phase II test and procurement plan represent the total program effort expended by Management, Engineering, Reliability and hardware supplier to design, produce, and test a burst disc that will be compatible with ground support and airborne requirements and environments.

1.1.4.1.1 Scope

The purpose of this test plan is to describe the testing methods, hardware procurement, test criteria and test objectives for design verification testing of burst disc improvements.

1.1.4.1.2 Object

The Phase II Test Program, will demonstrate through completion of the verification testing, a significant increase in reliability and operational performance. Improvements in burst disc design will eliminate the failure modes which exists in present hardware.

1.1.4.1.3 Test Philosophy

The reliability program has paralleled the design phases as all improvements in the hardware have been made to eliminate a definite failure mode or problem area.

Testing requirements are based on the reliability Failure Mode Analysis. The following list indicates the failure mode and the appropriate test that will provide design verification.

Failure Mode	Design Verification Test
Contamination	Sand and Dust
Corrosion	Salt Fog
Damage from externally applied loads	Vibration (1) Sine (2) Random
Shipping Damage	Shock
Structural Integrity of disc body	Proof Pressure
Assembly damage and seal stability	Disc Assembly - dis-assembly test

Basic Design Verification	
Verification of disc coating	Thermal Shock
Design Verification	Flow Test
Design Verification	Burst Pressure

1.1.4.1.4 Applicable Documents

The following documents form a part of this test plan to the extent specified herein:

SP-4-38-D	Acoustics and Vibration Environments and tests specification levels ground support equipment, Launch Complex 39.
NASA TMX-53023	Terrestrial Environment (Climatic) Criteria Guidelines for use in space vehicle development.
MIL-STD-810A (USAF)	Environmental Test Methods for Aerospace and Ground Equipment
MSFC-SPEC-279	Electronic Capability
KSC-STD-164D	Environmental Test Methods for Ground Support Equipment Installation at Cape Kennedy.

1.1.4.1.5 Test Requirements

Prior to and as a condition of acceptance, the supplier shall subject each unit to the acceptance tests of Table 8 in the sequence shown. The contractor reserves the option of reconducting any or all of the acceptance tests as receiving inspection.

TABLE 5	
Acceptance Tests	
Test	Page No.
Examination of Product	83
Functional Test	80
Proof Pressure	83
Burst Test (Sample)	83

Design Evaluation Tests (To be conducted by AMETEK/Straza)

TABLE 6	
Design Evaluation Tests	
Test	Page No.
Salt Spray	84
Sand and Dust	83
Sine Vibration	84
Random Vibration	84
Flow Test	83
Burst Test	83
Shock	84
Thermal Shock	84

Testing Sequence

Tests will be conducted in the sequence that is the most consistent with operational environments under normal installed conditions.

Testing Sequence (Continued)

Development Testing

A. Burst Disc Development

B. Disc Cutter Evaluation (Salt Fog Test)

Design Evaluation Testing

A. Disc Burst Test

B. Proof Pressure Test

C. Flow Test

D. Sand and Dust Test

E. Salt Fog Test

F. Shock Test

G. Thermal Shock Test

H. Sine Vibration Test

I. Random Vibration Test

Test Data Sheet

The test data sheet shall be filled out in its entirety and signed by all personnel involved in performance of the test at the time of test or immediately following the test.

Photographic evidence shall be made of the specimen following each individual test. The photographs shall be identified with date, type of test, specimen identification and any unusual condition present.

Test Report

A test report following the test program will be prepared. This report will include all facts and conclusions, which are the results of the tests. In addition, this report will contain a section entitled, "Recommendations." This section will contain suggestions regarding further design improvements which are a result of the test program.

1.1.4.1.6 Development Program

AMETEK/Calmec Burst Disc Development

The reverse buckling type burst disc proposed by the AMETEK/ Calmec Company requires a development program to establish several critical design parameters prior to hardware fabrication and subsequent design verification testing. This development includes:

A. Establishing the optimum burst disc material and thickness. The minimum materials to be tested include: 316L, Monel, Inconel and Nickel.

Knife blade materials to be tested are 17-7 PH and austenitic stainless steels. Both the disc diaphragm and knife blades will be evaluated bare, with a teflon coating, silicone coating and gold plating.

These coatings will be tested to determine the effect on burst tolerance, ease of application, consistency in producibility, and protection from corrosion.

B. Evaluation of the cutter blades in a corrosive salt fog atmosphere with and without plating or coating. Evaluation will be made of the cutting capability after salt fog tests and assembly of the knife blade into the burst disc assembly.

1.1.4.2 Test Procedure

1.1.4.2.1 Burst Disc Cutter

Stainless steel Burst Disc Cutters will be supplied to AMETEK/ Straza in the following configurations:

A. Unplated

B. Gold Plated

C. Teflon Coated

D. Silicone Coated

The specimens shall be placed in salt spray chamber and exposed to a solution of salt, 5 parts by weight in 95 parts by weight of water, at $5^{o}F$ for a period of 240 ± 2 hours. The specimens will be non-operating during this test.

Following the salt fog test the effects of the corrosive atmosphere will be determined by profilometer and shadowgraph template.

Upon completion of burst disc cutter evaluation, the cutters shall be installed into burst disc assemblies and a burst test performed to determine the sharpness of the cutter following the salt fog test.

This test and all subsequent design verification testing shall be performed in accordance with the requirements of KSC-STD-164D.

Upon determination of the optimum cutter, burst disc assemblies shall be fabricated incorporating these cutters and shipped to AMETEK/Straza for the completion of the Phase II Testing.

1.1.4.2.2 Burst Disc Assembly

Examination of Product

The burst disc shall be carefully examined to determine conformance to specification with respect to material, size, weight, construction, identification, marking and quality of workmanship.

Functional Test

The test specimen shall be evacuated by means of a helium mass spectrometer to 1×10^{-4} mm Hg or better. A plastic bag shall be placed over the outside of the specimen and helium admitted into the bag until all air is displaced. The leakage test shall be accomplished using a helium mass spectrometer set at a sensitivity of 1×10^{-8} scc/sec of helium. Following this leakage test, pressurize the specimen from 0 psig to 20 psig at a rate of increase in pressure not to exceed 5 psig per minute. Repeat leakage test after disc functional pressure test.

Burst Pressure Test

The burst test shall be conducted on three (3) specimens of each type tested. Each specimen shall be pressurized to 30 ± 5 psig at an increasing rate not to exceed 5 psig per minute.

Exact rupture pressure shall be recorded together with any variations that occur during test.

Proof Pressure Test

The proof pressure test shall be conducted on each specimen. The burst disc diaphragm shall be protected from the pressure and the specimen shall be pressurized with helium gas to a pressure of 150 psig and held for a period of two (2) minutes. During the pressure test, the specimen shall be leak tested. Following this test, the functional test shall be performed.

Flow Test

A flow test shall be conducted on each of the three (3) burst disc specimens used to test for burst pressure.

The flow rate shall be 350 cubic feet per minute (ft^3/min) of GN_2 warmed to a temperature of -110°F. Following this test, the functional test shall be performed.

Sand and Dust Test

The test specimen shall be exposed to sand and dust at an air velocity of 100 feet to 500 feet per minute at 77°F for a period of two (2) hours. At the end of this period, the temperature will be raised to 160° F and this condition will be maintained for an additional two (2) hours. The specimen will be non-operating with protective covers in place. Following this test, the functional test shall be performed.

Salt Fog Test

The test specimen shall be exposed to a solution of salt, 5 parts by weight in 95 parts by weight of water, at 95 $^{+2}_{-4}$ °F for a period of 240 ± 2 hours. The specimens will be non-operating with protective covers in place. Following this test, the functional test shall be performed.

Shock Test

The test specimen shall be subjected to peak shock pulse level of 30 g attained in 10 ± 1 milliseconds. The total pulse duration shall be 20 ±1 milliseconds. Following this test, perform functional test.

Thermal Shock - High Temperature

The specimen shall be exposed to an area flame at 1400°F $^{+100}_{-0}$ °F for a period of ten (10) seconds. Following the high temperature test, the specimen shall be subjected to the functional test.

Sine Vibration Test

The test specimen shall be subjected to sine frequency cycling along each of three (3) mutually major perpendicular axes. A frequency cycle shall consist of sweeping the frequencies from 20 to 2000 to 20 cps in ten (10) minutes. The rate of frequency change shall be logarithmic. All resonant frequencies will be recorded during the frequency cycling test. Following the sine vibration test, the specimen shall be subjected to the functional test.

Table 7. Sine Vibration Test		
Frequency	Search	Freq. Cycling
20 - 150	± 3.5 g	± 7.0 g
150 - 292	0.003 in. da.	0.006 in. da.
292 - 2000	± 13 g	± 26.0 g

Random Vibration Test

The test specimen shall be subjected to random vibration for a period of ten (10) minutes in each of three (3) mutually perpendicular axes at an ambient temperature.

Table 8. Random Vibration Test	
Frequency - CPS	Vibration Level
10 - 100	+ 6 DB/Octave
100 - 1000	.5 g^2/cps
1000 - 2000	-6 DB/Octave

Procurement Plan

Test Specimen Selection

Fike Metal Products and AMETEK/Calmec were selected for their capability to design and fabricate the Phase II test hardware. Selection was based on as comprehensive an evaluation as possible including: Design reviews, reliability design analysis, and elimination of failure modes established by failure mode analysis. Specimens to be procured include:

Fike:	Union type burst disc removable disc assembly. Ten units required.
Fike:	Union type burst disc all welded unit. Ten units required.
Calmec:	Union type burst disc removable disc assembly. Ten units required.

Miscellaneous seals of various elastomer compositions will be procured and evaluated.

1.2 PHASE II PROGRAM

The Phase II Test Program of the NASA Vacuum Jacketed Umbilical Lines Technology Advancement Program was conducted to evaluate design improvements needed to eliminate the problems that were being experienced at the Cape Kennedy launch complex with the presently installed burst discs.

The procurement specifications were mailed to burst disc manufacturers on a competitive quote basis for Phase II test specimens. The AMETEK/Calmec Company of Los Angeles, California, and the Fike Metal Products Company of Blue Springs, Missouri, were accepted as sources (see Figure 1). Black, Sivalls and Bryson (BS & B) submitted a design that was worthy of consideration for test, but could not be procured within budget requirements.

Prior to purchasing the test specimens a Burst Disc development program was completed to establish critical design parameters. This development program consisted of establishing the following design parameters:

1. Optimum burst disc material and thickness. This would give a thickness which would provide the confidence level in burst disc tolerance consistency prior to hardware manufacture.

2. A variety of disc and cutter coating materials for corrosion protection. These would be evaluated for their effect on burst tolerance, ease of application, and consistency in producibility.

3. Evaluation of cutter blades after exposure to corrosive atmosphere. The cutter blades were provided with and without plating for evaluation of the cutting capability after exposure to a corrosive atmosphere. The results of this development program are included as part of the final report.

In summary, the results were that Teflon, 17-7 PH for cutter, 304L stainless for the body is the recommended combination of materials that will meet the reliability requirements established for this hardware.

Purchase Orders were placed for thirty burst disc assemblies. AMETEK/Calmec supplied ten replaceable assemblies. Fike Metal Products supplied ten replaceable assemblies and ten all-welded assemblies (see Figure 1).

All units underwent receiving inspection and functional testing to determine conformance to vendor drawings and procurement specifications. Following this initial acceptance the test specimens were subjected to the Phase II testing program.

The Test Report, Para. 1.2.3, describes the results of tests conducted on Burst Discs during the Phase II program.

The Burst Discs were subjected to a test program simulating various natural and induced environments to determine compliance with KSC-STD-164D "Environmental Test Methods for Ground Support Equipment Installations at Cape Kennedy." This testing has provided the design evaluation information which is used as a basis for recommendation to NASA for future procurement of burst discs. The recommendations and conclusions for Phase I and Phase II are included following the Test Report.

The various tests that were performed have enabled AMETEK/ Straza to evaluate the test specimen under the most adverse environmental and operational conditions that are found at a launch complex at Cape Kennedy.

Tests that were conducted evaluated the basic design features and structural integrity of the specimen. Evaluation of the basic design included such tests as (1) Receiving Inspection, (2) Functional, (3) Burst Pressure, and (4) Proof Pressure. Environmental testing included (5) Salt Fog, (6) Sand and Dust. Operational tests included (7) Thermal Shock, (8) Shock, and (9) Vibration.

Specimens

The AMETEK/Calmec burst disc specimens purchased for this program were manufactured with a burst pressure of 30 to 40 psig. The following is the result of the Burst Disc Test.

Burst at 39 psig	4 Units
Burst at 40 psig	1 Unit
Burst at 41 psig	4 Units
Burst at 43 psig	1 Unit

Fike Metal Products burst disc specimens were purchased for this program were manufactured with a burst pressure of 30 ± 5 psig. The following is the result of the burst disc test.

Burst at 30 ± 5 psig	18 Units
Burst at 39 psig	1 Unit
Burst at 37 psig	1

Test Program Results

The Phase II test program validated the design concepts that were incorporated into test hardware. These concepts were determined during Phase I to be the solution to the burst disc field installation problems at Kennedy Space Center Complex 39.

1. Teflon coating of the diaphragm and cutter was successful in preventing corrosion.

2. The replaceable disc-cutter assembly was successfully removed and installed on the assembly without subsequent leakage even under the most adverse conditions following sand and dust test.

3. The externally threaded AMETEK/Calmec assembly allowed water to penetrate in the unit in the upside-down attitude. This is considered a design deficiency.

4. The Fike Metal Products flat seat on the replaceable disc required excessive torque (600 inch-pounds) to effect a seal. The Teflon gasket was distorted and unusable after one installation. Maintenance would be difficult with this seal.

5. The sealing weld on the Fike replaceable disc assembly is subject to manufacturing defects and stringent quality controls would be required to make it a reliable unit.

6. Functional testing after assembly of the specimens was completed for all specimens.

7. Proof pressure testing was completed on all specimens. No deformation was noted.

8. Salt fog testing was successful in showing the reliability of the Teflon coated diaphragm and cutter. No corrosion was noted.

9. Sand and dust testing was conducted with assembly/ disassembly operations also being performed successfully and without subsequent leakage.

10. Thermal shock was successful in establishing the resistance of the specimens and silicone Silastic 55 protective cap to $1400^{o}F$ flame for ten (10) seconds.

11. Shock testing was performed successfully without failure of any specimen.

12. Vibration testing was conducted on all specimens. AMETEK/ Calmec's retainer nut backed off at 1800 cps and will require either lockwire or internally threaded nut for retainment.

13. Burst testing was successful in showing the effects of damaged (dented) discs. The undamaged discs that were burst pressure tested were within specification allowable and exhibited a high degree of consistency.

Development Program - Burst Discs

This development program consisted of four (4) phases which included: Design, Labor, Development, Test and Material. AMETEK/Calmec provided the engineering, technical services and shop services necessary to determine the optimum design for a "reverse buckling" rupture disc. Calmec also performed the testing necessary for determining the correct rupture disc bulge height, material, knife blade material and optimum coating of both disc diaphragm and knife blade. The main purpose of this program was to determine the correct combinations of burst disc variables to assure a rupture disc and knife blade material that would ensure penetration of the disc diaphragm by the knife blade. It would also determine the effects of the coating on the disc diaphragm on rupture pressure tolerance. The disc diaphragm materials included 316L, Monel, Inconel, and Nickel. Knife blade material considered as a minimum included 17-7 PH, and austenitic stainless steels of as many types as time allowed to be tested. Coatings and platings that were to be evaluated included teflon and silicone coating, gold plating, and bare material. Following the development program, AMETEK/ Calmec supplied knife blade assemblies with the various coatings for preliminary salt fog corrosion tests. This test was performed prior to the final assembly of the knife blade into the burst disc assembly. Following the completion of salt fog tests on the cutters, a purchase order was placed for test specimens. The salient features of the results of this development program was (1) the angular seat and teflon coating of the disc to serve as the seal, (2) incorporation of the most current design concepts in the burst disc industry such as disc diaphragm and knife blade alignment, (3) plated knife blade, (4) teflon coated disc diaphragm.

1.2.1 Rupture Disc Development Report

The following test report prepared by the AMETEK/Calmec Company, reflects the test results compiled during this program. It describes the method of performance, results and recommendations. Several graphs are included showing material thickness in a pressure range of from 10 psig to 60 psig.

AMETEK/Calmec
5825 District Boulevard
Los Angeles, California 90022

Telephone: (213) 588-6204
TWX: 910-321-4353

BDS-1
1" UNION ASSEMBLY
RUPTURE DISC
DEVELOPMENT REPORT

PREPARED FOR: AMETEK/Straza

PREPARED BY: C. D. Anderson

DATE: 6/13/69

CDA:bb

APPROVED BY: F. R. O'BRIEN s/s
F. R. O'Brien
Project Engineer

1" UNION ASSEMBLY
RUPTURE DISC
DEVELOPMENT REPORT

CONTENTS

1" UNION ASSEMBLY
RUPTURE DISC
DEVELOPMENT REPORT

I. REASON FOR TEST

The purpose of this test is to determine the kind of material, thickness of material and equipment settings required to manufacture rupture discs to customer's specifications.

To determine the thickness, a number of discs must be pressurized to destruction.

II. DESCRIPTION OF TEST APPARATUS

The major portion of the testing is accomplished in a hydraulic press designed by the manufacturer to form the rupture disc. The panel board on this press is equipped with the following Supergauges manufactured by U. S. Gauge, Division of AMETEK, Inc.:

Fig. No.	Range	Accuracy	Calibrated
1803	0-600	± 1/2%	May 10, 1969
1803	0-100	± 1/2%	May 10, 1969

The remainder of the testing is accomplished in a union assembly that is fastened to the panel board.

III. TEST PROCEDURE

Forming the material to the required rupture pressure is a function of the kind of material, thickness of material and draw pressure on the press.

The following procedure is used to achieve the required rupture pressure:

1. Determine kind of material to be tested.
2. Select one thickness of this material.
3. Select a draw pressure on press and form disc.
4. Pressurize disc to destruction.

1" UNION ASSEMBLY
RUPTURE DISC
DEVELOPMENT REPORT

Steps 3 and 4 may be repeated, selecting different draw pressures.

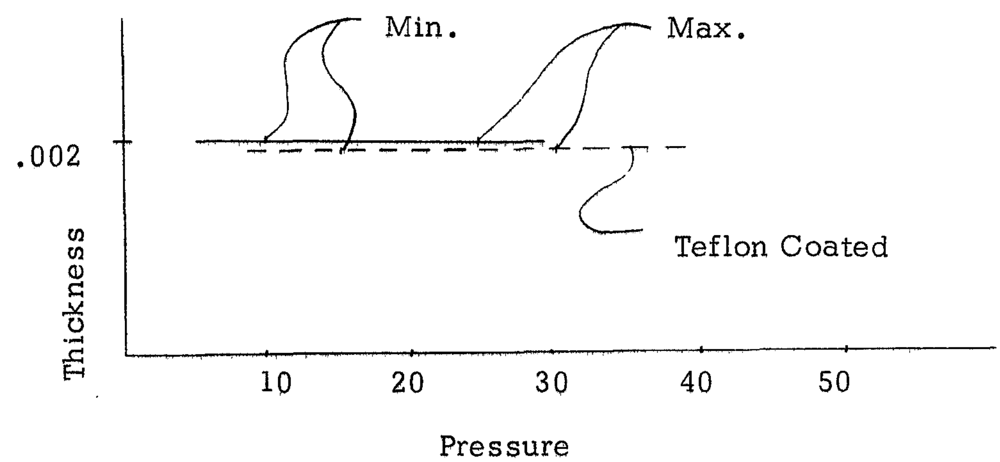
If rupture pressure is not in range of customer specifications with this thickness of material, repeat 2, 3 and 4 with another thickness of material.

This procedure is to be followed for each kind of disc material specified by the customer.

IV. RESULTS OF TESTS, SUMMATIONS AND ANALYSIS

Materials selected for the test were Inconel, Nickel, 316L Stainless Steel and Monel. The knife blade would not properly penetrate the disc on the 316L Stainless Steel and Monel when formed to the required rupture pressure.

The following graphs will indicate pressure range per material thickness on materials tested.



.002 Thick Inconel

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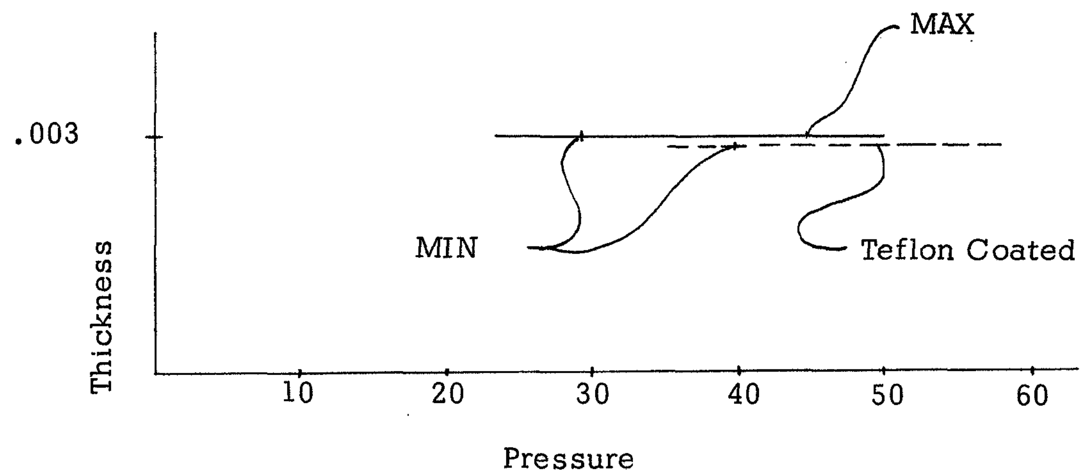
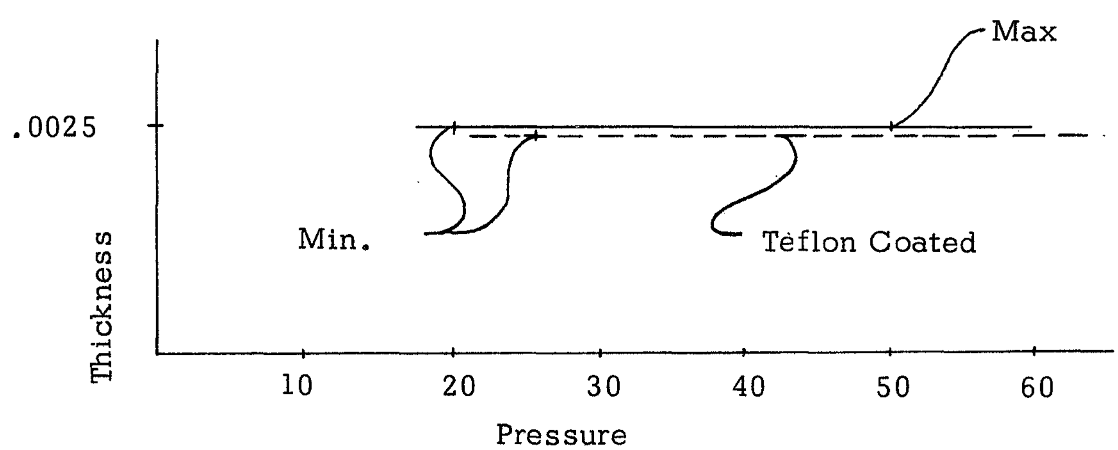


.003 Thick Inconel

Maximum Teflon Coated rupture pressure was not determined on this test.



.0025 Thick Nickel

Maximum Teflon Coated rupture pressure was not determined on this test.

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RUPTURE DISC
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The minimum mark on each graph is the minimum pressure that the reverse acting disc would snap through and get the proper knife blade penetration required.

The maximum mark on each graph is the maximum pressure that the reverse acting disc will snap through and maintain repeatability.

Teflon coating the disc will increase the rupture pressure of the disc. This increase varies with thickness of the disc material.

The .0025 thick nickel was selected as the material to be used. The following rupture pressures is test made with selected thickness and draw pressure.

Not Coated	Coated
30 PSI	36 PSI
30 PSI	35 PSI
34 PSI	37 PSI
33 PSI	36.5 PSI
34 PSI	37 PSI
33 PSI	35 PSI

V. SUPPLEMENTS

A. Helium Mass Spectrometer Test

1. Customer leakage requirement not to exceed 1×10^{-7} STD CC of He/sec.
2. Equipment: CEC Consolidated Electro-dynamics Corporation Leak Detector 24-120B (Calmec Equip. No. 2109)
3. Test Results

   (a) Unit tested with a copper protective cover:

   Torque - 150 ft.-lb.
   Leakage - $>1 \times 10^{-4}$ SCC of He/sec.

1" UNION ASSEMBLY

RUPTURE DISC
DEVELOPMENT REPORT

(b) Unit without copper protective cover:

Torque - 150 ft.-lb.
Leakage - 3 X 10^{-8} SCC of He/sec.

A torque of 150 ft.-lb. was the maximum practical torque that could be applied. The leakage exceeded customer requirements; therefore it was determined that the copper protective cover could not be used and maintain the 1 X 10^{-7} SCCS of He specified.

B. DAMAGED DISC TEST

This was a test to determine what the results would be on a disc that had a dent in the crown caused by handling or dropping.

A dent approximately 1/2" diameter was placed in the crown of the disc. The unit was then attached to a vacuum pump to determine how much of the dent could be drawn out. The vacuum was .01 microns of Hg. Approximately 90% of the dent was removed.

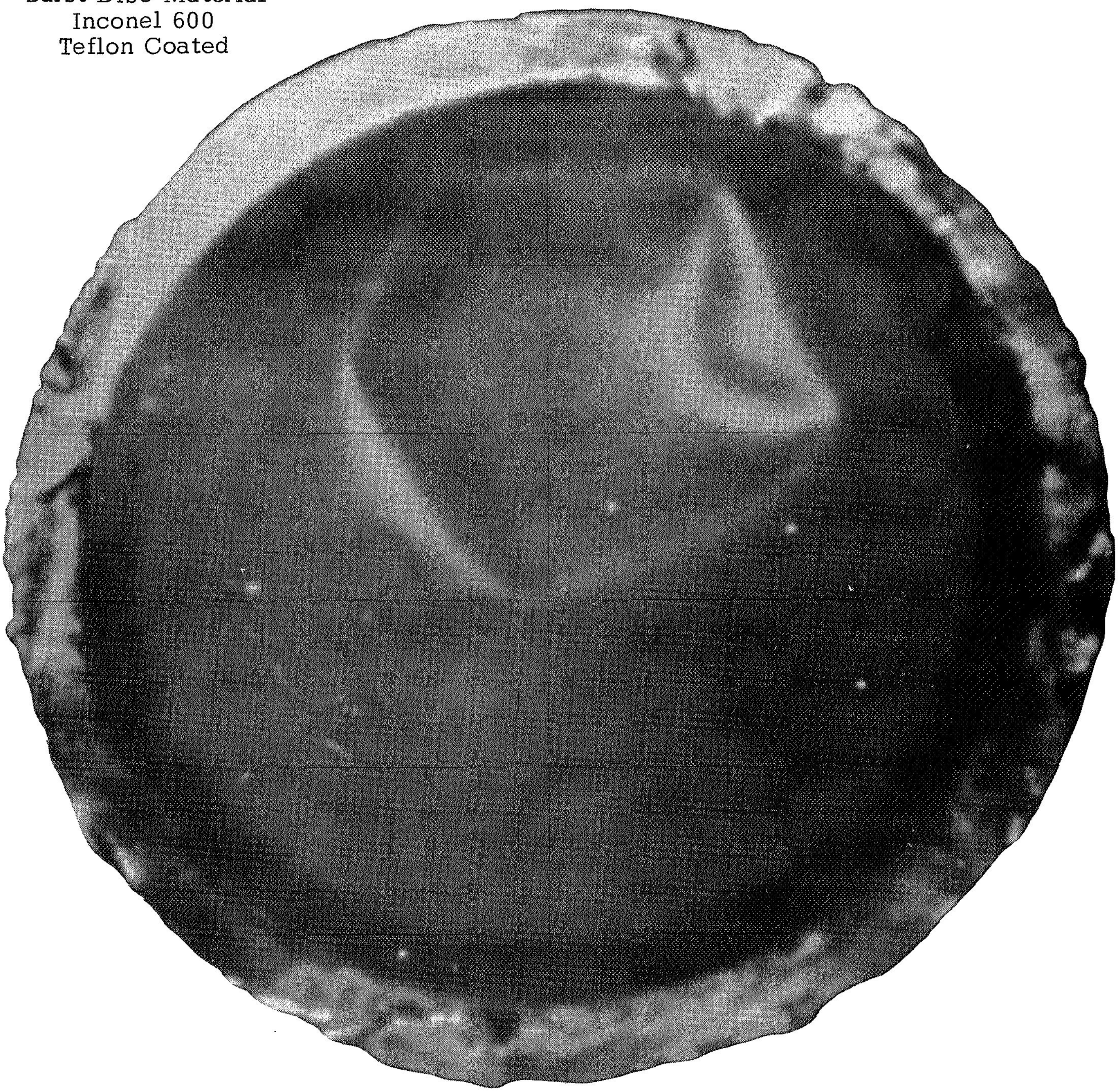
Pressure was then applied to the unit. The disc collapsed at 12 PSI. At 30 PSI knife blade penetrated disc so that it ruptured.

The conclusion of this test is that a damaged disc if used will fail at a lower pressure than specified.

C. CUTTER TEST

A test was conducted using several stainless steels to determine which material would perforate the .0025 nickel diaphragm. 304, 321 and 17-7PH were tested. 17-7PH afforded a superior cutting edge and was the only material that would adequately perforate the nickel diaphragm.

Burst Disc Material
Inconel 600
Teflon Coated

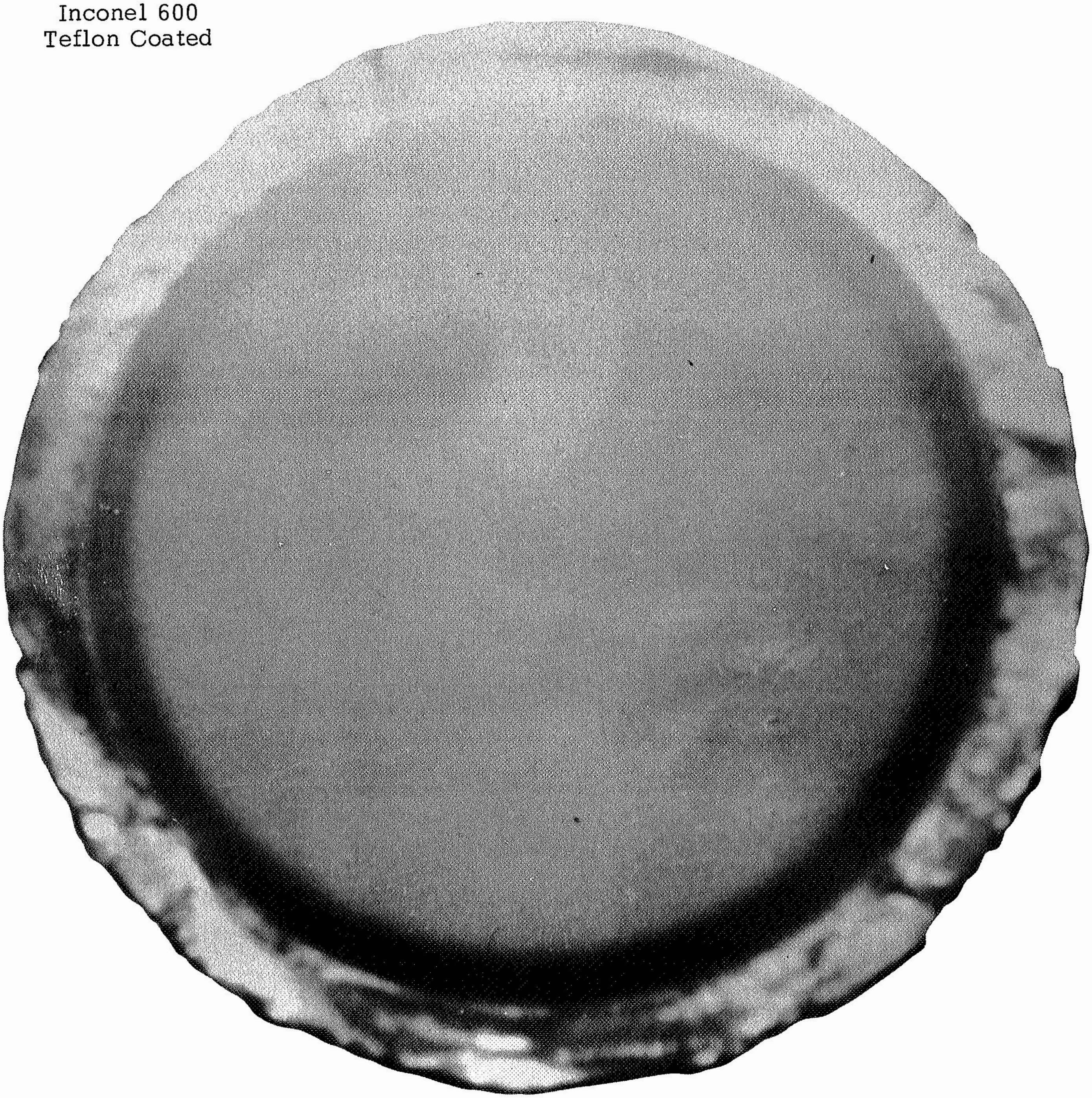


Depression Approximately
1/2" Mean Diameter

Burst Disc Diaphragm
AMETEK/Calmec Burst Disc

Figure 20. Burst Disc Diaphragm, With Dent

Burst Disc Material
Inconel 600
Teflon Coated



1/2" Mean Diameter Depression
After Subjected to Vacuum
(Note That Depression is Still in Evidence)

On Pressure Testing, Unit Buckled
at 12 psig — Ruptured at 30 psig

Burst Disc Diaphragm
AMETEK/Calmec Burst Disc

Figure 21. Burst Disc Diaphragm

1.2.2 Analysis — Burst Disc Forming and Reverse Snap Buckling Pressure

A design objective of the burst disc development of the NASA Vacuum Jacketed Lines Technology Advancement Program has been to provide an analytical method for calculating the reverse buckling pressure of a burst disc. An approach to the predetermination of reverse buckling pressure is necessary to permit comprehensive establishment of design parameters. The primary parameters considered are material, material thickness, diameter, dome height, forming pressure, and reverse buckling pressure. This analytical method herein developed affords the designer the opportunity to calculate the desired burst disc parameters for a specific application. (Figure 22, following the analysis, shows the forming of material to determine by measurement the amount of bi-directional stretch.)

SUMMARY OF ANALYSIS METHOD

The method outlined is based on empirical information obtained from tests by the Calmec Division of AMETEK in forming the hemispheres and by extrapolation from the test data on reverse snap buckling of the hemisphere, published in NACA Technical Note #3212, Titled "A Nonlinear Theory of Bending and Buckling of Thin Elastic Shallow Spherical Shells", by A. Kaplan and Y. C. Fung. An adjustment was made for the variable slip that Calmec personnel used to permit the thinner foils to actually slip from under the die hold down. The initial data on elongation and yield strength of the Inconel 600 foil were given Straza by the Calmec Division of AMETEK, along with the forming and reverse snap buckling pressures and the dome heights. Chord lengths were obtained by measurement of the reflected image of the hemisphere on the Straza comparator, and the material thickness by measurement with pin micrometers. The radius, half angle and arc length were calculated from equations given in Machinery's Handbook.

In calculating the forming pressure, a value must be established for the stress based on the cold work elongation. This was done by calculating the arc length elongation and subtracting an allowance for slip in the die hold down clamp. The forming is done in two stages, first the flat bottom cup is formed in the lower die with hydraulic pressure applied from the top, then hydraulic pressure is applied on the bottom face, for the second stage to reverse the cup into the hemispherical shaped upper die cavity. See sketches on the following page.

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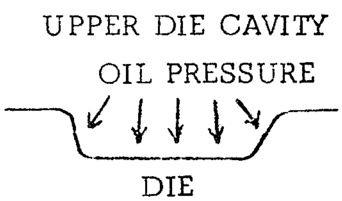
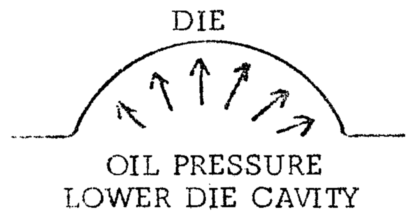
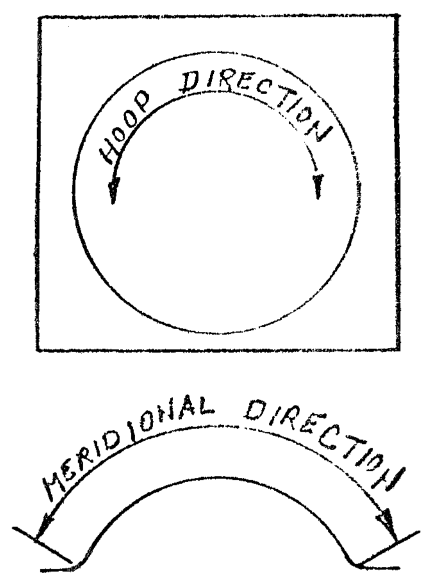


1ST STAGE



2ND STAGE



SKETCH SHOWING
ELONGATIONAL DIRECTIONS

The elongation in the shell takes place in the meridional and hoop directions (shown in the sketches on the preceding page). At the hold down the elongation is all meridional, although no correction was made for this.. The meridional and hoop elongations were assumed to be equal, then combined and subtracted from the initial material elongation to provide a residual elongation. The residual elongation is used to determine the equivalent yield stress from the curve published by Huntington Alloys in Bulletin T-7, Page 6, Figure 3, for Inconel 600. The forming pressure required can then be calculated from the equation for a hemispherical pressure vessel $P = {}^{2st}/R$.

The reverse snap buckling pressure is a non linear function, and a search of the current literature indicated very little information is available on this subject. NACA Technical Note #3212, Titled "A Nonlinear Theory of Bending and Buckling of Thin Shallow Spherical Shells" by Kaplan and Fung (also reproduced in a condensed form by Libove in Flugges' Handbook of Engineering Mechanics, pages 44-38 and -39) provided the information necessary to establish an empirical curve. This NACA Report was limited to a geometrical parameter λ equal to ten, where λ (Lambda) is a non-dimensional ratio function of the chord, thickness, radius and poissons ratio. For our case λ varied from thirty (30) to forty-four (44), however plots of Kaplan and Fung's data combined with test data from Calmec indicated a good correlation. See Curves on Pages 116 & 117 . The plot of the thinner foils (2 and 3 mil) did show some inaccuracies, but this may be due to the difficulty of obtaining accurate readings of elongations and yield tension stresses in the 2 to 3 mil range. The dome wall thickness (diaphragm thickness) from the chord to the crown varied from approximately 17 to 33 % respectively. It was empirically determined that the mean thickness value is located at the centroid of the dome where one half the included angle is equal to 38°. This averages out to 23.5% thinning of the initial material thickness. The variations in thinning from chord to crown indicates that the cold work varies directly as the thinning rate. For these reverse buckling calculations the empirical thinning value of 23.5% has indicated reverse buckling pressures within 10% of tested values. It is planned that in the future a mathematical solution will be developed to predict the individual thinning value. Additional testing and refinement of the equations used will enhance the accuracy in predicting the forming and reverse snap buckling pressures. Two graphs on pages 116 & 117, were made to compare the combined NACA

3212 and the Calmec Test data with the Calmec test data alone. The results show that it is feasible to use the method outlined to predict forming and reverse snap buckling pressures for hemispheres.

GLOSSARY

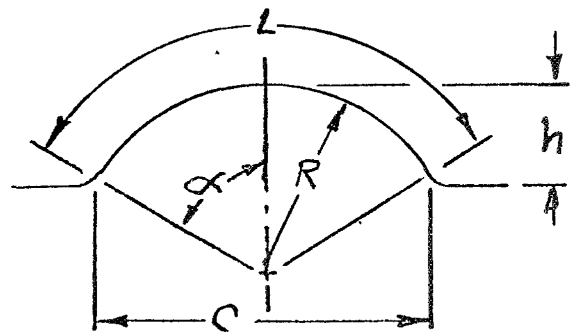
R	=	Radius of Dome
C	=	Chord - measured at flange, minimum radius
h	=	Dome height
α	=	1/2 included angle measured between flange minimum radius bend
L	=	Arc length
E_L	=	Percent elongation by forming
E_C	=	Actual Metal elongation (forming elongation minus slip)
S	=	Slip, portion of dome material acquired by stock sliding under clamp during forming (The 9% to 3% values for slip are empirically determined for the forming equipment used for the test specimens).
E_B	=	Biaxial Elongation
E_R	=	Residual Elongation, % of elongation remaining after forming (Ultimate elongation minus biaxial elongation).
P	=	Dome forming pressure
F_{TY}	=	Yield Stress for material
t_2	=	Mean thickness after forming
λ	=	Reverse snap buckling parameter
ν	=	Poissons ratio
R_C	=	Dimensionless buckling load parameter, empirically determined (See Graph)
E	=	Modulus of Elasticity

The following calculations are a step-by-step example analysis used to determine the diaphragm metal thickness and its corresponding reverse buckling pressure.

RADIUS

$$R_{2-2} = \frac{C^2 + 4h^2}{8h}$$

REF: Machinery's Handbook 14th Edition, Page 152



$C_{2-2} = 2.0823$ In. for 2 mil tests

$$R_{2-2} = \frac{\overline{2.0823}^2 + 4\,(.5277)^2}{8 \times .5277}$$

$$= 1.2909 \text{ In}$$

$$\alpha = \text{ARCSIN}\,\frac{C/2}{R}$$

$$= \text{ARCSIN}\,\frac{\frac{2.0823}{2}}{1.2909}$$

$$= 53^\circ - 45' \text{ Half Angle}$$

$$L = 2 \times \frac{\alpha\, R}{57.296}$$

$$= 2 \times \frac{53.75 \times 1.2909}{57.296}$$

$$= 2.4216 \text{ In.}$$

$$h_{2-2} = .5277 \text{ In.}$$

AMETEK / Straza

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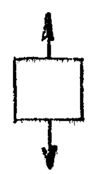
CALCULATIONS

Elongation $E_L = \frac{L - C}{C} 100$

$$= \frac{2.4216 - 2.0823}{2.0823} 100$$

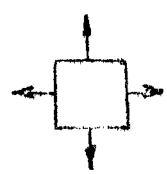
$$= 16.29\%$$

E_C (Uniaxial Elongation) $= 16.29 - 9.0$



$= 7.29\%$

E_B (Biaxial Elongation) $= 2 \times 7.29\%$



$= 14.58\%$

E_R (Residual Elongation) $= 26.7 - 14.58$

$= 12.12\%$

From Huntington Alloys Bulletin T7, Page 6 F3, The equivalent stress for 12.12% elongation $F_{TY} = 109$ KSI

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CALCULATIONS

Forming Pressure $P = \dfrac{2\,F_{TY}\,t_2}{R}$

$$= \frac{2 \times 109{,}000 \times .00147}{1.2909}$$

$$= 248 \text{ PSI} < 260 \text{ PSI Actual or } -4.6\% \text{ error}$$

Reverse Snap Buckling Parameter λ

$$\lambda = .931C\left(\frac{\sqrt{1-\nu^2}}{t_2 R}\right)^{1/2}$$

REF: NACA TN3212, - A Non-Linear Theory of Bending and Buckling of Spherical Shells by Kaplan & Fung.

ν = .29 Poissons Ratio for Inconel 600

$$\lambda = .931 \times 2.0823 \left(\frac{\sqrt{1 - .29^2}}{.00147 \times 1.2909}\right)^{1/2}$$

$$= 43.52$$

$$P = \frac{R_{cR}\,E}{(1-\nu^2)}\left(\frac{t_2}{C/2}\right)^4$$

REF: Handbook of Engineering Mechanics by Flügge Pg 44-33, Case 2.

$E = 31 \times 10^6$ PSI REF: Huntington Alloys Bulletin T-7, Page 4, Table 4.

t_2 = .00147 See Page 8, Test Number 2, This Report.

AMETEK / Straza

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CALCULATIONS

R_{CR} = 1.63×10^5 A dimensionless buckling load parameter from graph on Page 116.

$$P = \frac{1.63 \times 10^5 \times 31 \times 10^6}{1 - .29^2} \left(\frac{.00147}{2.0823/2}\right)^4$$

= 22 PSI Reverse Snap Buckling Pressure

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Inco 600 Test		Test Pressure			Wall thickness in mils t_2 From flat to Crown					Dome					Elong.
No	Thk Mils	Form psi	Snap psi	Crown Ht in.	0^o	30^o	60^o	90^o	Mean@ $38^o t_2$	Chord* C in.	Rad R in.	Half Angle	Arc Lt L in.	Arc-Ch'd / Ch'd 100 %
1	2	260	22	.5309	1.6	1.6	1.5	1.4	1.57	2.0848	1.2958			
2	↓	↓	22	.5277	1.6	1.5	1.4	1.4	1.47	2.0823	1.2909	53^o-45'	2.4216	16.29
3			22	.5245	1.65	1.5	1.5	1.4	1.47	2.0874	1.3007	53^o-22'	2.4225	16.06
1	3	430	45	.5679	2.6	2.3	2.2	2.2	2.27	2.0843	1.2402	57^o-11'	2.4751	18.75
2	↓	↓	41	.5691	2.4	2.4	2.3	2.3	2.37	2.0823	1.2369	57^o-19'	2.4742	18.82
3			41	.5758	2.6	2.3	2.2	2.1	2.27	2.0806	1.2277	57^o-56'	2.4823	19.31
1	4	630	115	.5698	3.5	3.1	2.85	2.8	3.07	2.0846	1.2382	57^o-20'	2.4776	18.85
2	↓	↓	120	.5677	3.3	3.2	2.85	2.8	3.17	2.0844	1.2405	57^o-09'	2.4742	18.70
3			120	.5709	3.4	3.1	2.85	2.7	3.07	2.0844	1.2367	57^o-26'	2.4789	18.93

*CHORD LT. = DIST BETWEEN TANGENT PTS OF CORNER RAD. TO DOME

PHYSICAL PARAMETERS AND TEST DATA FOR REVERSE BUCKLING PRESSURE OF SPECIMENS

Inco 600 Test		1 Initial Condition		2	3	4	5			
No	Thick Mils	Yield Stress KSI	Elong. %	Calc. Elong. %	Assum. Slip %	Adjust Uniaxial Elong % 2 - 3	Adjust Biaxial Elong % 4 X 2	Residual Elong 1 - 5 %	Equiv. Plastic Yield Stress F_{TY} * KSI	Forming Press PSI $P = \frac{2F_{TY}\ t_2}{R}$
1	2	45.7	26.7	This piece was used for display purposes						
2				16.29	9.0	7.29	14.58	12.12	109	248
3				16.06	9.0	7.06	14.12	12.58	108	244
1	3	40.2	31.3	18.75	9.0	9.75	19.50	11.80	112	410
2				18.82	9.0	9.82	19.64	11.48	113	433
3				19.32	9.0	10.32	20.64	10.66	115	425
1	4	46.9	40.5	18.85	3.0	15.85	31.70	8.80	118	585
2				18.70	3.0	15.70	31.40	9.10	117	598
3				18.93	3.0	15.93	31.86	8.14	120	596

* REF: HUNTINGTON ALLOYS BULLETIN T-7 PAGE 6, FIGURE 3

TABLE OF CALCULATED PARAMETERS (SHEET 1 OF 2)

AMETEK / Straza

ENGINEERING REPORT

BJECT: Rupture Disk

C. Urbanac

CHECKED:

NO:

DATE: 8/19/69

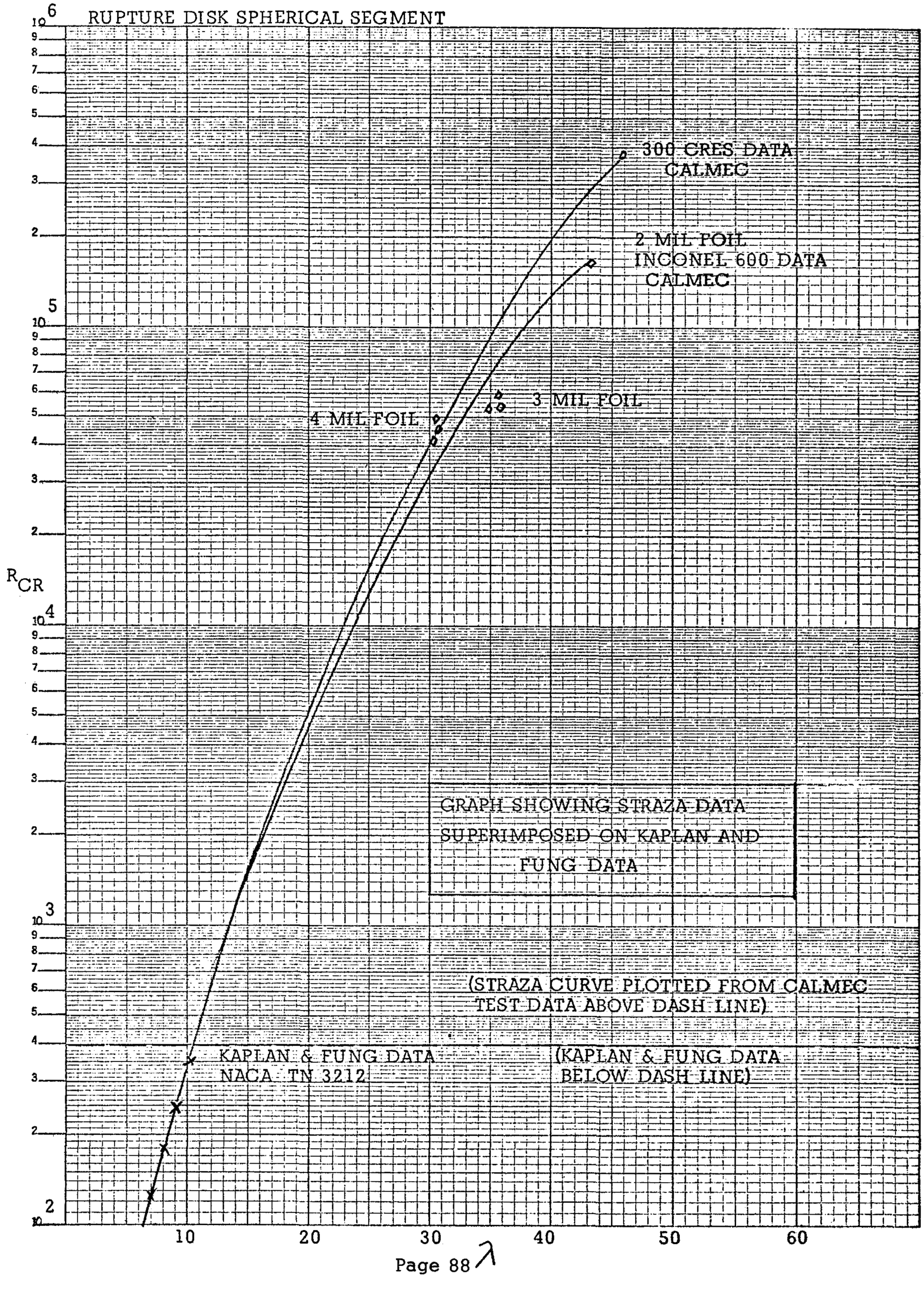
PAGE OF

JOB NO: 4056

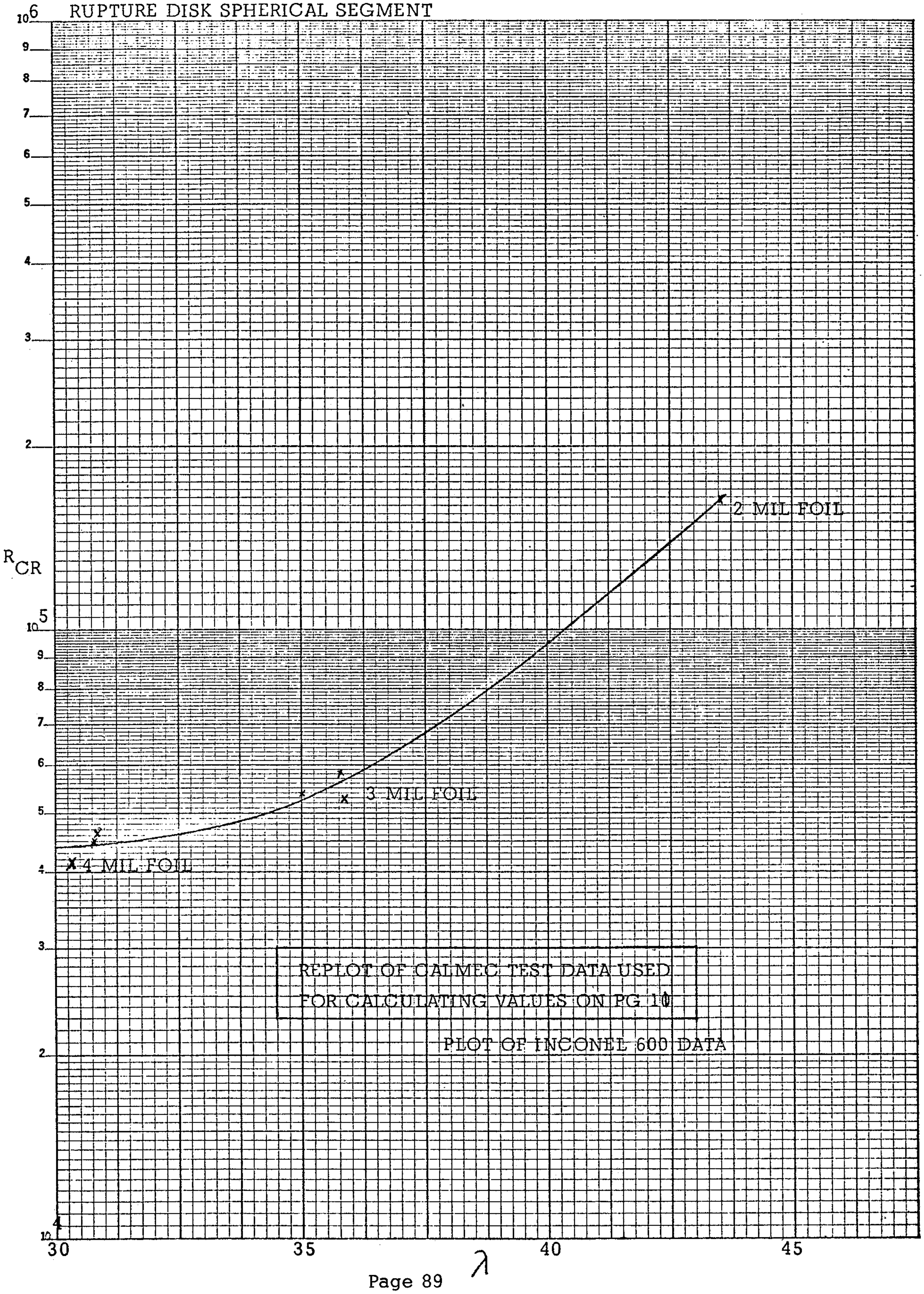
Inconel 600 Test No	Inconel 600 Thick Mils t	λ Geometric Parameter $\lambda = .931C\left(\frac{\sqrt{1-\nu^2}}{t_c R}\right)^{1/2}$	R_{CR} Load Parameter $\times 10^{-5}$	t_c Calculated Mean Thick in Mils $= .765\ t_c$	Empirical Reverse Buckling Pressure PSI $P = \frac{R_{CR}E}{1-\nu^2}\left(\frac{t_c}{C/2}\right)^4$	Percent Deviation of Reverse Buckling Pressure
1	2	42.64	1.42	1.53	22.3	+1.4
2		42.67	1.43		22.5	+2.3
3		42.62	1.42		22.3	+1.4
1	3	35.54	.553	2.30	44.4	-0.1
2		35.56	.554		44.5	+8.5
3		35.66	.558		44.8	+9.3
1	4	30.84	.441	3.06	110.8	-7.7
2		30.81	.440		110.5	-7.9
3		30.86	.442		111.1	-7.4

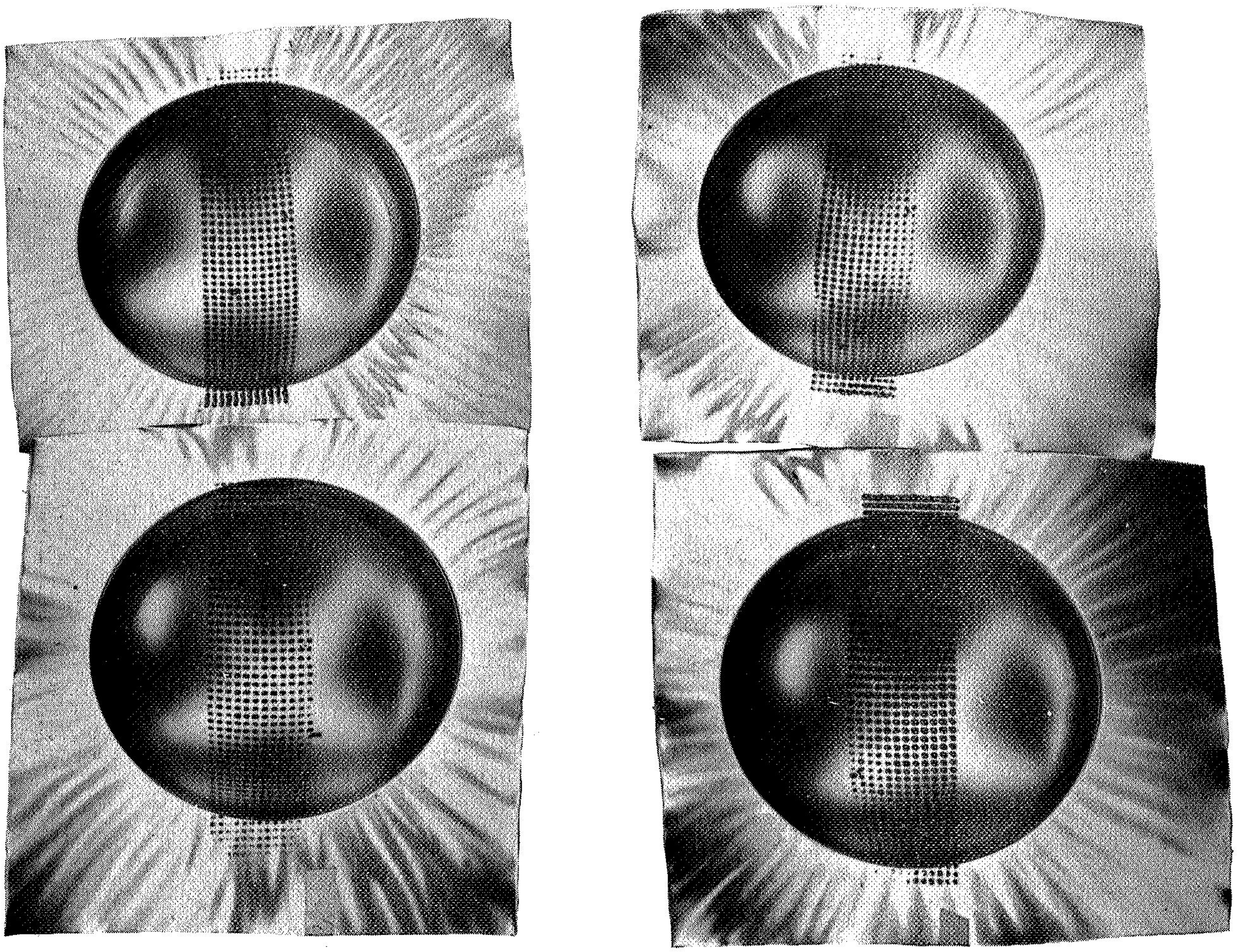
$*\ \nu = .29$ FOR INCONEL 600; $E = 31 \times 10^6$ PSI

TABLE OF CALCULATED PARAMETERS (SHEET 2 of 2)

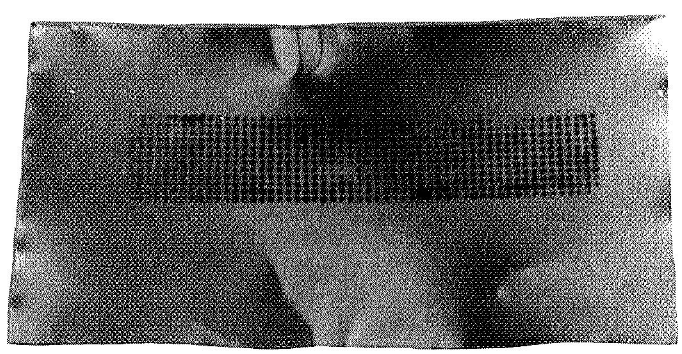

RUPTURE DISK SPHERICAL SEGMENT
300 CRES DATA
CALMEC
2 MIL FOIL
INCONEL 600 DATA
CALMEC
3 MIL FOIL
4 MIL FOIL
GRAPH SHOWING STRAZA DATA
SUPERIMPOSED ON KAPLAN AND
FUNG DATA
(STRAZA CURVE PLOTTED FROM CALMEC
TEST DATA ABOVE DASH LINE)
KAPLAN & FUNG DATA
NACA TN 3212
(KAPLAN & FUNG DATA
BELOW DASH LINE)
R_{CR}
λ

RUPTURE DISK SPHERICAL SEGMENT





NOTE:
Grid pattern indicates amount of material bi-directional stretch.



Burst Disc Diaphragm After Forming
1-1/2 Inches Diameter

Figure 22. Burst Disc After Forming

1.2.3 TEST REPORT

1.2.3.1 Scope

The purpose of the Phase II test program of the NASA Vacuum Jacketed Umbilical Line Technology Advancement Program was to validate the design of Burst Discs developed during the Phase I study portion of the program.

Testing was conducted in accordance with NASA approved test procedures to meet the requirements of KSC-STD-164D "Environmental Test Methods for Ground Support Equipment Installations at Cape Kennedy."

Manufacturers

AMETEK/Calmec
5825 District Boulevard
Los Angeles, California

Fike Metal Products
704 South Tenth Street
Blue Springs, Missouri

1.2.3.2 Item Description

Test Specimen Part Number	Test Specimen Serial Number	Type
Calmec RDS-106	1 through 10	Burst Disc Replaceable Assembly
Fike A3856	1 through 10	Burst Disc Replaceable Assembly
Fike A3857	1 through 10	Burst Disc All Welded
Dow Corning Silicone Material	N/A	Silastic 55 for protective covers

Quantity of Items Tested

Thirty (30)

Testing Conducted By

AMETEK/Straza
790 Greenfield Drive
El Cajon, California

1.2.3.3 Applicable Documents

NASA Contract NAS10-6098

AMETEK/Straza Test Procedure 8-480087

KSC-STD-164D "Environmental Test Methods for Ground Support Equipment Installations at Cape Kennedy."

Phase I Technical Report, Task I, Burst Discs

1.2.3.4 Tolerances

Ambient

Temperature	75 ±15°F
Pressure	30 ±2 in. Hg
Relative Humidity	80% or less

Test

Pressure	±5%
Temperature	Below 100°±10°F Above 100°±5°F
Relative Humidity	+5% to -0%
Vibration Amplitude	±5%
Vibration Frequency	±2% or 1 cps, whichever is greater

Instrument Pressure

Pressure	±0.5%
Flow	±2%
Temperature	±1%
Vibration Amplitude	±1%

1.2.3.5 Requirements

All general requirements of KSC-STD-164D apply to tests described in this document. At the conclusion of each environmental test, the test item was to be visually inspected for signs of damage and deterioration and met the requirements of the functional test of Paragraph 1.2.3.6.2.

The test item was to be installed in the test fixture in a manner that simulated service usage.

Each test specimen completed all Phase II test requirements. Test results that were identical for test specimens of the same type were combined on one (1) data sheet. Combined data sheets included: basic part number, serial numbers, test requirement, and results. Data sheets were combined only for parts of the same type which had undergone the same test and which had demonstrated identical results.

Any reference to vacuum seal valves and vacuum probes in this report is due to the fact that these components underwent salt fog and sand and dust test at the same time.

1.2.3.6 TESTS PERFORMED

1.2.3.6.1 Receiving Inspection

Purpose

This inspection of the specimen was made to determine conformance with applicable drawings and specifications to the extent possible without disassembly of the test item.

Requirements

The receiving inspection includes the following:

A. Identification of test items by marking or tagging to establish manufacturer's part number and serialization.

B. Visual inspection to establish the "as received condition" and verify that the items' configuration and external dimensions are in conformance with the applicable drawings and specifications.

C. Photograph and weigh one item of each part number.

Procedure

Inspection procedure included the following:

A. A check of manufacturer, part number and serial number of each item.

B. Statement of condition of each item.

C. Dimensions of each item.

D. Photograph and weight one of the items of each part number.

E. Material certification.

Results

All AMETEK/Calmec specimens met the requirements of AMETEK/Calmec Drawing No. RDS-106 and were in acceptable condition. All Fike specimens met the requirements of Fike drawings A 3856 and A 3857 and were in acceptable condition. All specimens were electro-etched to include serial numbers, weighed and photographed.

Material certifications were received with the specimens. Material was acceptable.

Test Data

The following test data sheets reflect the results of the Receiving Inspection.

DESIGN VERIFICATION TEST

RECEIVING INSPECTION DATA SHEET

BURST DISCS

Each specimen shall be examined to determine conformance to Specification 8-410020 as follows:

Material 304L S.S.

Dimensions within envelope Reqt ✓ Yes ___ No

Construction WELDED

Identification ELEC. ETCH

Quality of Workmanship GOOD

Weight: Actual 9 OZ Max Allow. 20 OZ

Ten (10) specimens FIKE Part Number A 3857-1

	Accepted	Rejected
Serial Number 1	☑	☐
Serial Number 2	☑	☐
Serial Number 3	☑	☐
Serial Number 4	☑	☐
Serial Number 5	☑	☐
Serial Number 6	☑	☐
Serial Number 7	☑	☐
Serial Number 8	☑	☐
Serial Number 9	☑	☐
Serial Number 10	☑	☐

Test Engineer J. Martins Inspector M. [illegible]

Date of Test 7-7-69

DESIGN VERIFICATION TEST

RECEIVING INSPECTION DATA SHEET

BURST DISCS

Each specimen shall be examined to determine conformance to Specification 8-410020 as follows:

Material 304 S.ST.

Dimensions within envelope Reqt ✓ Yes ___ No

Construction SINGLE PIECE

Identification ELEC. ETCH

Quality of Workmanship GOOD

Weight: Actual 9 OZ. Max Allow. 20 OZ.

Ten (10) specimens FIKE Part Number A3856-1

	Accepted	Rejected
Serial Number 1	☑	☐
Serial Number 2	☑	☐
Serial Number 3	☑	☐
Serial Number 4	☑	☐
Serial Number 5	☑	☐
Serial Number 6	☑	☐
Serial Number 7	☑	☐
Serial Number 8	☑	☐
Serial Number 9	☑	☐
Serial Number 10	☑	☐

Test Engineer J. Martin Inspector M. Klee

Date of Test 7-7-69

DESIGN VERIFICATION TEST

RECEIVING INSPECTION DATA SHEET

BURST DISCS

Each specimen shall be examined to determine conformance to Specification 8-410020 as follows:

Material 304 S.S.

Dimensions within envelope Reqt ✓ Yes ___ No

Construction SINGLE PIECE

Identification METAL TAG

Quality of Workmanship GOOD

Weight: Actual 16 OZ. Max Allow. 20 OZ.

Ten (10) specimens CALMEC Part Number RDS 106

	Accepted	Rejected
Serial Number 1	☑	☐
Serial Number 2	☑	☐
Serial Number 3	☑	☐
Serial Number 4	☑	☐
Serial Number 5	☑	☐
Serial Number 6	☑	☐
Serial Number 7	☑	☐
Serial Number 8	☑	☐
Serial Number 9	☑	☐
Serial Number 10	☑	☐

Test Engineer J. Martins Inspector [illegible]

Date of Test 6-29-69

1.2.3.6.2 Functional Test (First Assembly Following Receiving Inspection)

Requirement

This initial functional test was to be made to determine that the test item would function within the parameters of the burst disc specification after assembly. The specimens were assembled in a manner that simulates field assembly. Figure 23 shows the mass spectrometer leak test being performed on several burst disc assemblies.

Procedure

A. Leakage

After installing the burst diaphragm and seals and torquing the disc to the specified limit, the assembled burst discs were leak tested by means of a helium mass spectrometer. The inlet side was evacuated to 1×10^{-4} mm Hg or better and helium sprayed on the outlet side. Leakage allowable 1×10^{-7} std cc/sec of helium (see Figure 23).

B. Pressure Test

Following the leakage test, the specimens were pressurized with nitrogen gas to 20 ±2 psig at a moderate rate of pressure increase not to exceed 5 psig per minute and held for 2 minutes. Following the pressure test, the leakage test as described in "A" above, was repeated. The test item was photographed at the conclusion of the test and the following data recorded: (1) Leakage rate before and after test; (2) test pressure; (3) test media; (4) duration and effects.

Results

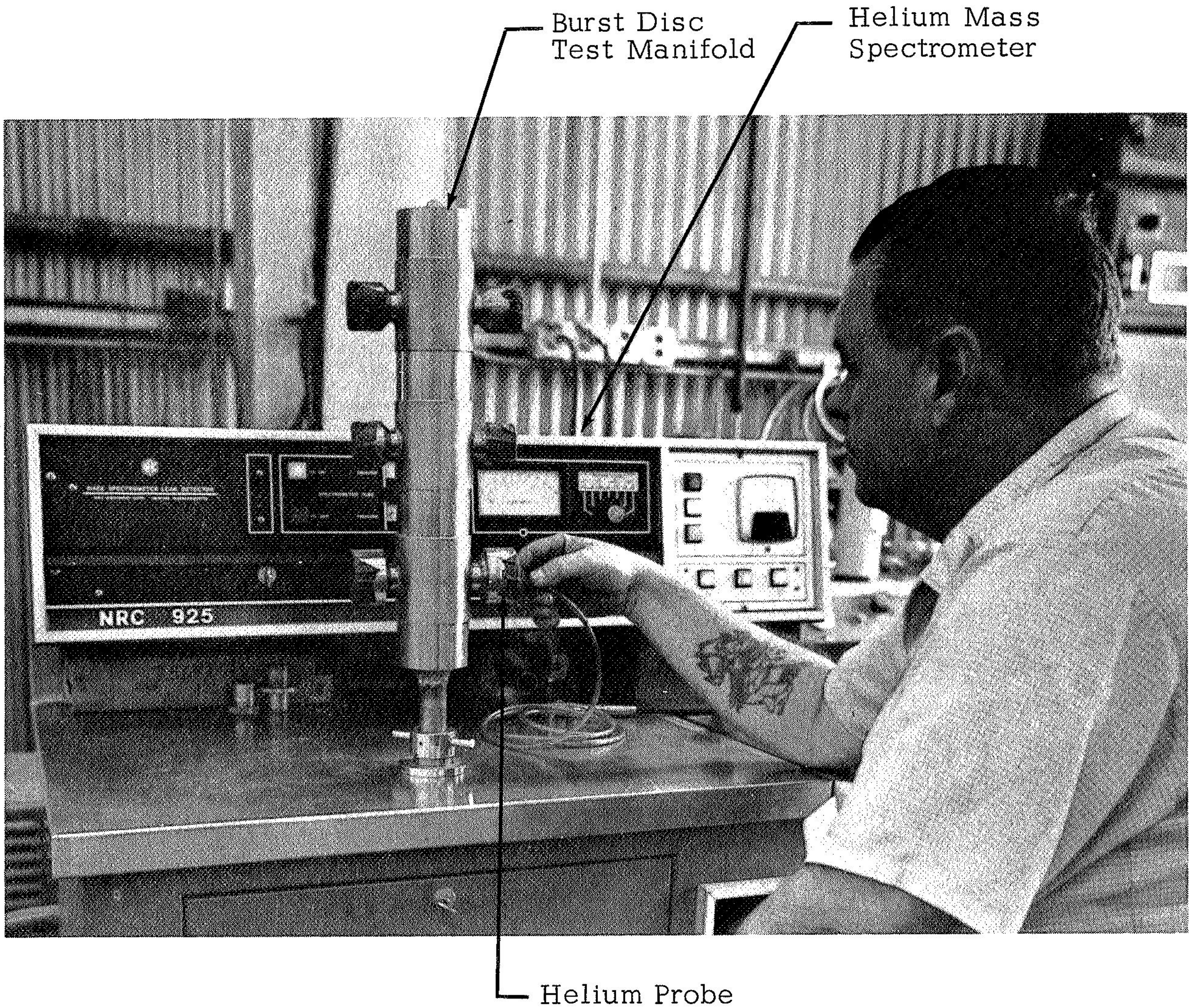
A. The AMETEK/Calmec specimens were: (1) Easily assembled; no leakage was evident before or after pressure test, and (2) no detrimental effect was visible from the pressure test.

B. The Fike specimens (replaceable assemblies) were: (1) Difficult to assemble and ensure vacuum-tight seal; (2) damage to teflon seal is incurred due to high torque required (600 inch-pounds); (3) no detrimental effect was visible from the pressure test.

C. The Fike all-welded disc: (1) No leakage before or after pressure test; (2) no detrimental effect from the pressure test.

Test Data

The following data sheets and photographs reflect the results of the functional test.



Functional Test Burst Discs

Figure 23. Functional Test-Burst Discs

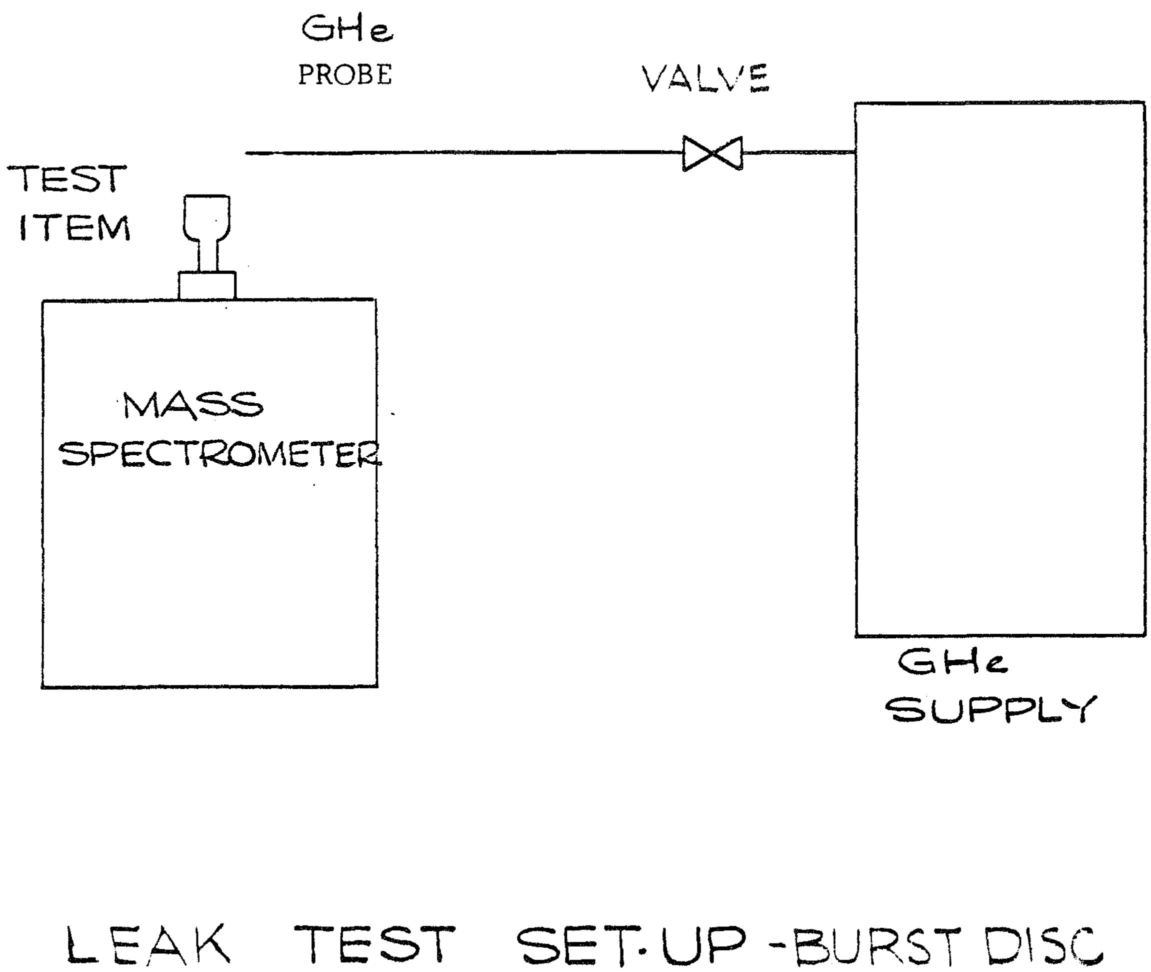


Figure 24. Leak Test Set-up

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional | Date of Test: 8-1-69

Part Name: Burst Disc | Part Number: A 3857-1

Test Procedure: 8-440087, Para 5.2 | Part Serial Number: 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure: 20 ±2 psig

Test Media: GN_2

Duration of Test: 2 min.

Remarks

1. All welded unit. No assembly of disc required.
2. No detrimental effect from functional pressure test
3. This test was performed prior to proof pressure test (Para. 5.3)

Test Technician: L. McKnight s/s

Test Engineer: J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-1-69

Part Name Burst Disc Part Number A 3856-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 3

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

1. Torque valve required to effect seal: 600 in.-lb.
2. No detrimental effect from functional pressure test.
3. This test performed prior to proof pressure test (Para. 5.3)
4. Disc body sealing surface required polishing to remove a scratch 0.001 x 3/8 in. long. Replaceable disc assembly was also polished to remove scratches.

Test Technician L. McKNIGHT S/S

Test Engineer J. Martins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional — Date of Test: 8-1-69

Part Name: Burst Disc — Part Number: A 3856-1

Test Procedure: 8-440087, Para 5.2 — Part Serial Number: 1, 2, 4 - 10

A. Leakage

Leak Rate Before Pressure Test: $< 1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure Test: $< 1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure: 20 ±2 psig

Test Media: GN_2

Duration of Test: 2 min.

Remarks

1. Torque valve required to effect seal: 600 in.-lb.
2. No detrimental effect from functional pressure test
3. This test performed prior to proof pressure test (Para. 5.3)

Test Technician: L. McKNIGHT s/s

Test Engineer: V. Mattrie

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-1-69

Part Name Burst Disc Part Number RDS-106

Test Procedure 8-440087, Para 5.2 Part Serial Number 10

A. Leakage

Leak Rate Before Pressure Test $< 1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

1. Torque valve required to effect seal: 150 in.-lb.
2. No detrimental effect from functional pressure test.
3. This test performed prior to proof pressure test (Para. 5.3)
4. Large metal chip (0.150 dia.) trapped between disc and body resulted in leakage. Chip was removed with no detectable leakage upon re-test.

Test Technician L. McKNIGHT 5/5

Test Engineer J. Matting

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional   Date of Test: 8-1-69

Part Name: Burst Disc   Part Number: RDS-106

Test Procedure: 8-440087, Para 5.2   Part Serial Number: 1 - 9

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure: 20 ±2 psig

Test Media: GN_2

Duration of Test: 2 min.

Remarks

1. Torque value required to effect seal: 150 in.-lb.
2. No detrimental effect from functional pressure test.
3. This test performed prior to proof pressure test (Para. 5.3)

Test Technician: L. McKNIGHT 5/5

Test Engineer: J. Martins

1.2.3.6.3 Proof Pressure Test

Requirement

The specimen body was subjected to 150 ±3 psig with GN_2 for a duration of 2 minutes. The specimen was photographed and distortion, defects, and data recorded. Following the proof pressure test, the functional leak test was performed (see Figure 25).

Procedure

The specimens were disassembled and the burst diaphragm replaced with blind caps. The all-welded units were pressurized on both sides of the burst disc using a special fixture. The specimens were placed in an unrestrained position and pressurized per the above requirement.

Test Results

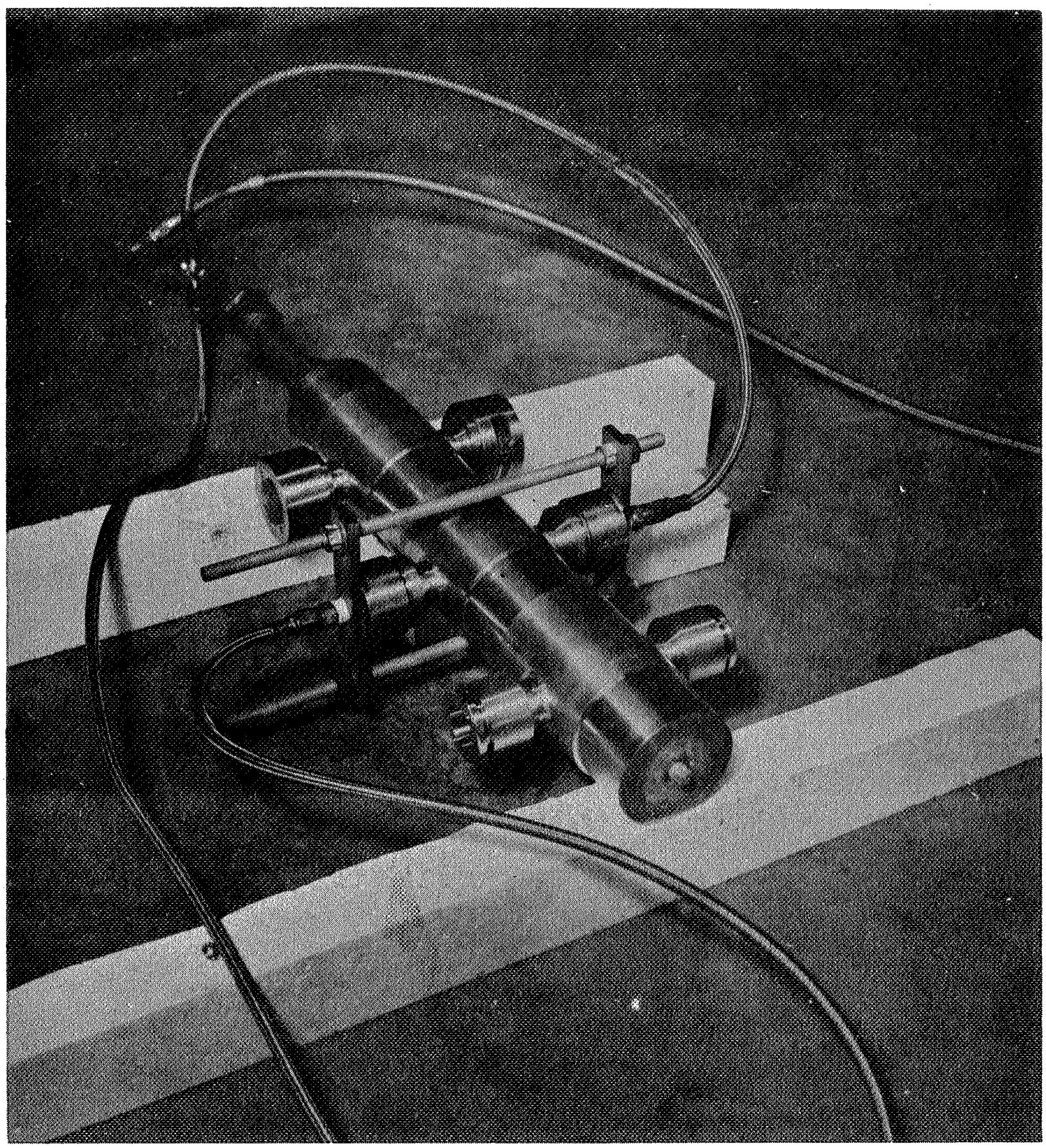
A. AMETEK/Calmec RDS-106 withstood proof pressure without deformation or defects.

B. Fike A3856 and A3857 withstood proof pressure without deformation.

C. Functional leakage test indicated no leakage except for Fike A3857 Serial No. 10. Pressure separated the disc diaphragm from a weld.

Test Data

The test data sheets and photographs reflect the results of the proof pressure test.



Proof-Pressure Test of Burst Discs

Figure 25. Proof Pressure Test - Burst Disc

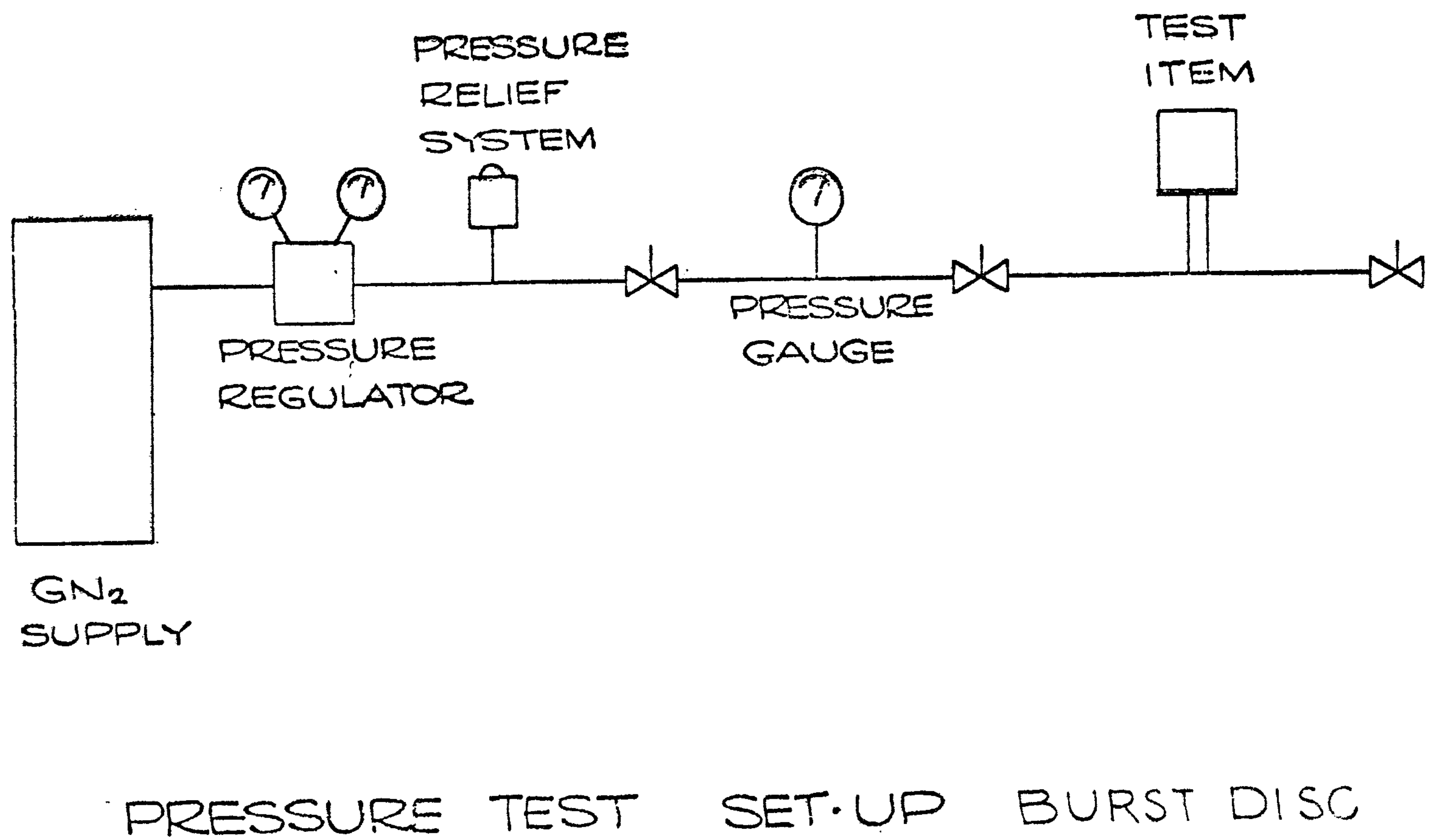


Figure 26. Pressure Test Set-Up - Burst Disc

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Proof Pressure   Date of Test: 8-5-69

Part Name: Burst Discs   Part Number: As Shown

Test Procedure: 8-480087   Part Serial Number: As Shown

Test Pressure: 150 psig   Test Media: GN_2 Duration of Test: 2 min.

	Manufacturer	Serial Number	Remarks
1.	Calmec RDS-106	1	No visible deformation — no detrimental effect.
2.	Calmec RDS-106	2	No visible deformation — no detrimental effect.
3.	Calmec RDS-106	3	No visible deformation — no detrimental effect.
4.	Calmec RDS-106	4	No visible deformation — no detrimental effect.
5.	Calmec RDS-106	5	No visible deformation — no detrimental effect.
6.	Calmec RDS-106	6	No visible deformation — no detrimental effect.
7.	Calmec RDS-106	7	No visible deformation — no detrimental effect.
8.	Calmec RDS-106	8	No visible deformation — no detrimental effect.
9.	Calmec RDS-106	9	No visible deformation — no detrimental effect.
10.	Calmec RDS-106	10	No visible deformation — no detrimental effect.
11.	Fike A 3856-1	1	No visible deformation — no detrimental effect.
12.	Fike A 3856-1	2	No visible deformation — no detrimental effect.
13.	Fike A 3856-1	3	No visible deformation — no detrimental effect.
14.	Fike A 3856-1	4	No visible deformation — no detrimental effect.
15.	Fike A 3856-1	5	No visible deformation — no detrimental effect.
16.	Fike A 3856-1	6	No visible deformation — no detrimental effect.
17.	Fike A 3856-1	7	No visible deformation — no detrimental effect.
18.	Fike A 3856-1	8	No visible deformation — no detrimental effect.
19.	Fike A 3856-1	9	No visible deformation — no detrimental effect.
20.	Fike A 3856-1	10	No visible deformation — no detrimental effect.
21.			
22.			
23.			
24.			

Test Technician: L. McKNIGHT /s/   Test Engineer: J. Martini

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Proof Pressure — Date of Test: 8-5-69

Part Name: Burst Disc — Part Number: As Shown

Test Procedure: 8-480087 — Part Serial Number: As Shown

Test Pressure: 150 psig — Test Media: GN_2 — Duration of Test: 2 min.

	Manufacturer	Serial Number	Remarks
1.	Fike A 3857-1	1	No visible deformation — no detrimental effect.
2.	Fike A 3857-1	2	No visible deformation — no detrimental effect.
3.	Fike A 3857-1	3	No visible deformation — no detrimental effect.
4.	Fike A 3857-1	4	No visible deformation — no detrimental effect.
5.	Fike A 3857-1	5	No visible deformation — no detrimental effect.
6.	Fike A 3857-1	6	No visible deformation — no detrimental effect.
7.	Fike A 3857-1	7	No visible deformation — no detrimental effect.
8.	Fike A 3857-1	8	No visible deformation — no detrimental effect.
9.	Fike A 3857-1	9	No visible deformation — no detrimental effect.
10.	Fike A 3857-1	10	No visible deformation — no detrimental effect.
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			
21.			
22.			
23.			
24.			

Test Technician: L. McKnight S/S — Test Engineer: J. Martin

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-7-69

Part Name Burst Disc Part Number A 3857-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 10

A. Leakage

Leak Rate Before Pressure Test $< 1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test was performed after proof pressure test (Para. 5.3)

Leakage occurred through the disc at 6×10^{-7} scc/sec following proof pressure

Unit was repaired and test sequence was continued per A & B

Test Technician L. A) E KNIGHT 5/5

Test Engineer T. Mastins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional — Date of Test: 8-7-69

Part Name: Burst Disc — Part Number: A 3857-1

Test Procedure: 8-440087, Para 5.2 — Part Serial Number: 1 - 9

Remarks

This test was performed after proof pressure test (Para. 5.3)

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician L. McKNIGHT 8/5

Test Engineer J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional — Date of Test: 8-7-69

Part Name: Burst Disc — Part Number: A 3856-1

Test Procedure: 8-440087, Para 5.2 — Part Serial Number: 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure: 20 ±2 psig

Test Media: GN_2

Duration of Test: 2 min.

Remarks

This test was performed after proof pressure test (Para. 5.3)

Test Technician: L. McKNIGHT S/S

Test Engineer: V. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-7-69

Part Name Burst Disc Part Number RDS-106

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1\times10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1\times10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test was performed after proof pressure test (Para. 5.3)

Test Technician L. McKNIGHT 5/5

Test Engineer J. Martine

1.2.3.6.4 Salt Fog Test - Burst Disc Cutter

Requirements

The burst disc cutters are tested to determine the surface condition that would best resist the salt fog environment prior to fabricating the burst disc cutter and diaphragm assembly.

The test specimens are to be subjected to 240 hours of exposure in a salt fog atmosphere of 5% salt and 95% water at $95^{\circ}F \; ^{+2^{\circ}}_{-4^{\circ}} F$ The cutter points are measured before and after testing. The specimens are allowed to stand until thoroughly dry and are then photographed.

Procedure

Four (4) 304 stainless and four (4) 17-7PH stainless burst disc cutters with four (4) surface conditions were to be prepared for testing (unplated, gold plated, silicone coated and teflon coated) .

Prior to testing, the cutter points were to be measured using a comparator with a magnification of 31 1/4 to 1. The specimens were to be suspended in the test chamber, as shown in Figure 27, and subjected to the salt fog atmosphere. Following the salt fog test, the specimen points were to be measured using the comparator to determine the extent of corrosion on the cutter points. The specimens were to be photographed at the conclusion of the salt fog test while still in the test position.

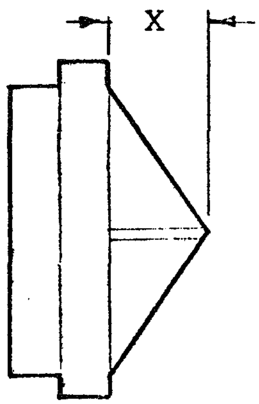
Results

The 304 and 17-7PH stainless cutters which were gold plated exhibited excessive corrosion and flaking-off of the gold plating over the entire surface. The bare cutters of both types corroded heavily on the welds. The silicone coated cutters of both types showed slight corrosion on the welds and the silicone peeled excessively due to handling. The teflon coated cutters showed no corrosion over any of the surface. The teflon coated cutter (cutter and disc diaphragm) showed .003 inch of material removed from the secondary cutter points, although the primary cutter was not affected (see page 146).

Test Data

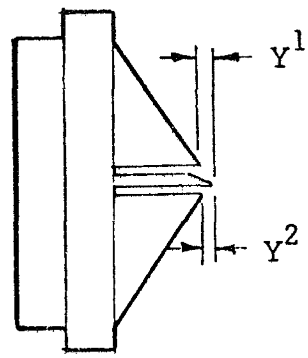
The following data sheets reflect the results of the test.

FIGURE I



Right angle with
one piece cutter
(Side view of part)

FIGURE II



Right angle with solid
cutter edge. Bevel edge up.
(Side view of part)

Serial Number Designation - 304 Stainless

S/N 1	-	Gold Plated
S/N 3	-	Teflon Coated
S/N 5	-	Bare 304
S/N 7	-	Silicone Coated

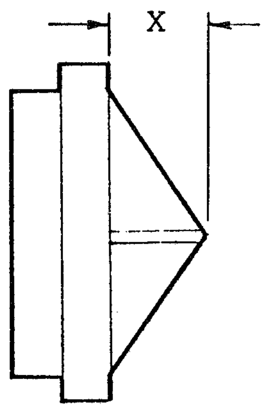
Before Salt Fog Test

Figure I	Figure II	
S/N 1 X = .068	S/N 1 Y^2 = .036	Y^1 = .030
S/N 3 X = .075	S/N 3 Y^2 = .070	Y^1 = .074
S/N 5 X = .085	S/N 5 Y^2 = .076	Y^1 = .070
S/N 7 X = .073	S/N 7 Y^2 = .070	Y^1 = .065

After Salt Fog Test

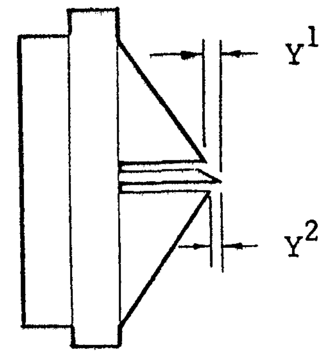
Figure I	Figure II	
S/N 1 X = .068	S/N 1 Y^2 = .035	Y^1 = .030
S/N 3 X = .075	S/N 3 Y^2 = .070	Y^1 = .074
S/N 5 X = .084	S/N 5 Y^2 = .075	Y^1 = .070
S/N 7 X = .073	S/N 7 Y^2 = .070	Y^1 = .064

FIGURE I



Right angle with
one piece cutter.
(Side view of part)

FIGURE II



Right angle with solid
cutter edge. Bevel edge
up. (Side view of part)

Serial Number Designation - 17-7PH Steel

S/N 2	-	Gold Plated
S/N 4	-	Teflon Coated
S/N 6	-	Bare 17-7PH
S/N 8	-	Silicone Coated

Before Salt Fog Test

Figure I	Figure II
S/N 2 X = .098	S/N 2 Y^2 = .081 Y^1 = .061
S/N 4 X = .089	S/N 4 Y^2 = .075 Y^1 = .085
S/N 6 X = .086	S/N 6 Y^2 = .075 Y^1 = .083
S/N 8 X = .084	S/N 8 Y^2 = .075 Y^1 = .075

After Salt Fog Test

Figure I	Figure II
S/N 2 X = .097	S/N 2 Y^2 = .080 Y^1 = .060
S/N 4 X = .089	S/N 4 Y^2 = .072 Y^1 = .082
S/N 6 X = .086	S/N 6 Y^2 = .073 Y^1 = .081
S/N 8 X - .083	S/N 8 Y^2 = .074 Y^1 = .074

Salt Fog Test Chamber (With Burst Disc
Cutter Assemblies Prepared for Test)

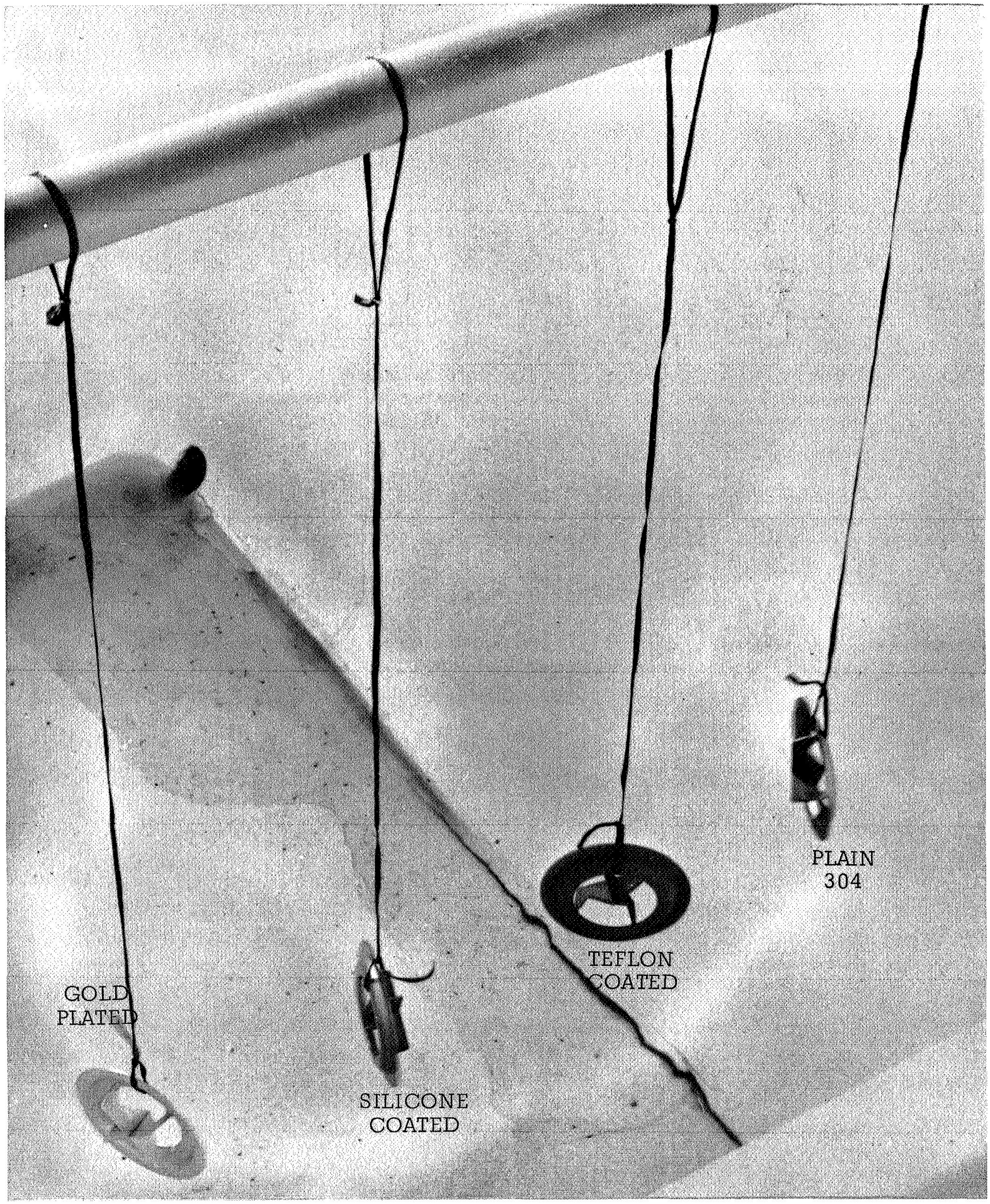
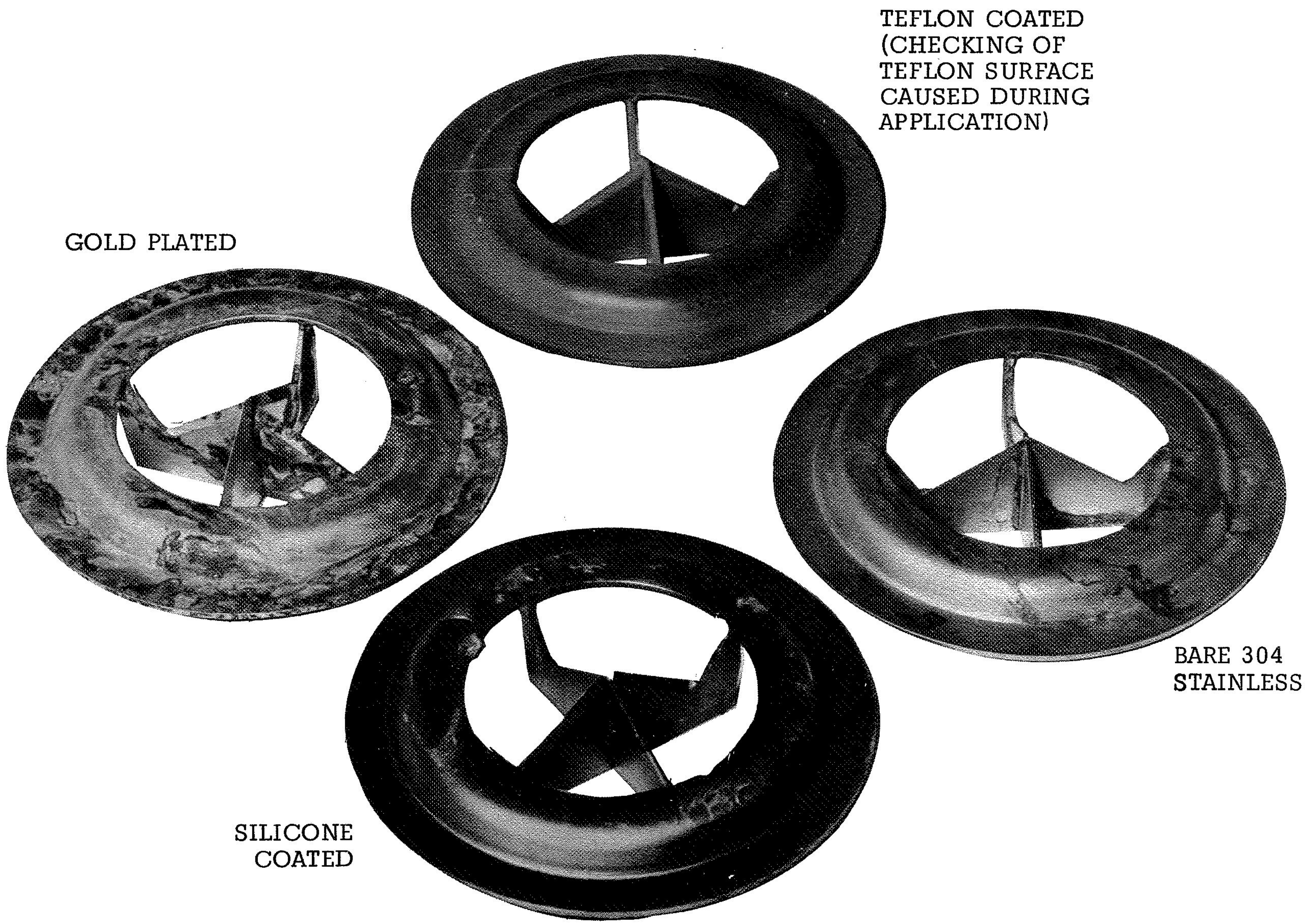


Figure 27. Salt Fog Test - Burst Disc Cutters



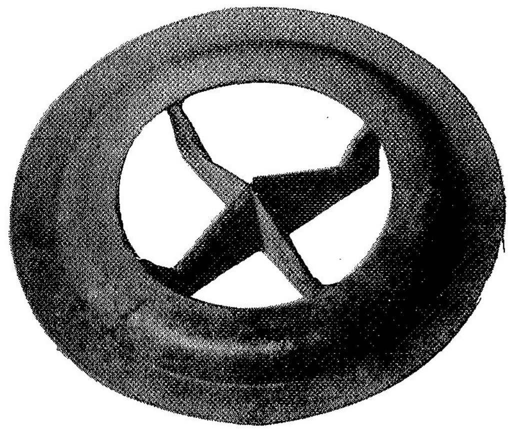
Burst Disc Cutter Assemblies
304 Stainless — After Salt Fog Test

Figure 28. Salt Fog Test - Burst Disc Cutters

Burst Disc Cutter Assemblies
304 Stainless — Prior to Salt Fog Test

Figure 29. Salt Fog Test - Burst Disc Cutters

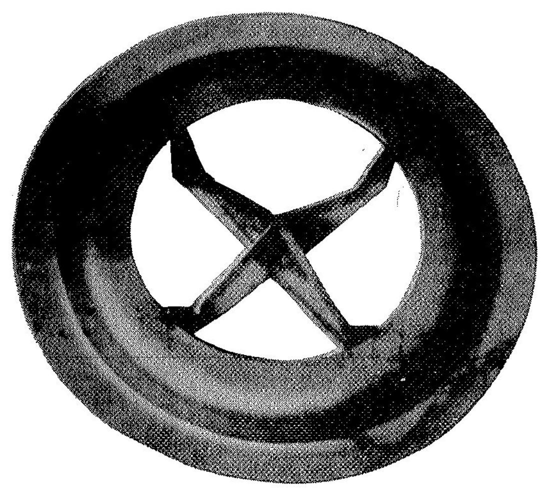
AMETEK/Calmec Burst Disc
Burst Disc Cutter Assemblies
17-7PH — After Salt Fog Tests



Teflon Coated
Cutting Edge and
Point Unaffected

Gold Plated
Showing Complete
Deterioration

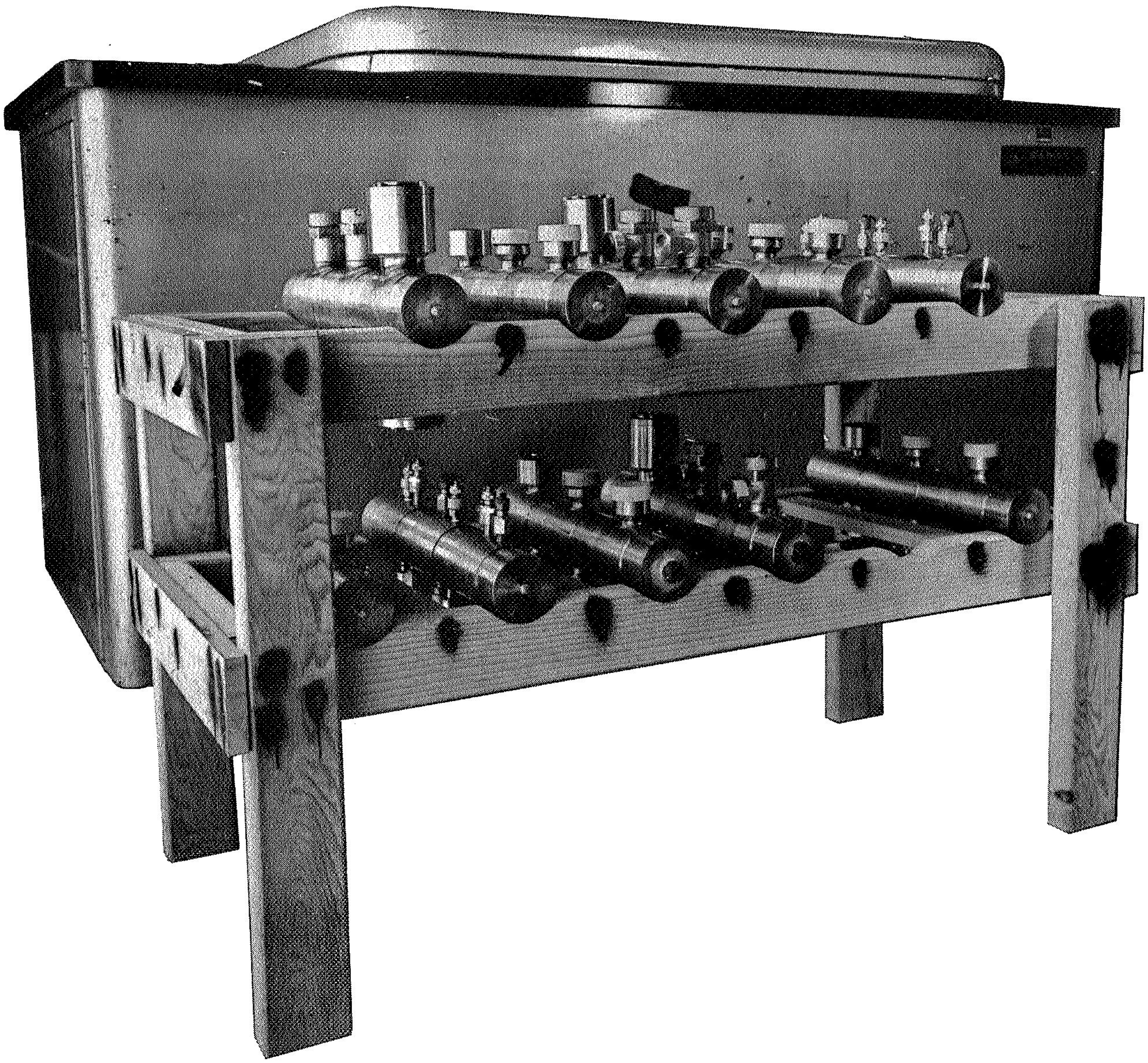
Silicone Coated
Minor Corrosion
At Welds



Rare 17-7PH
Note Corrosion
At Welds

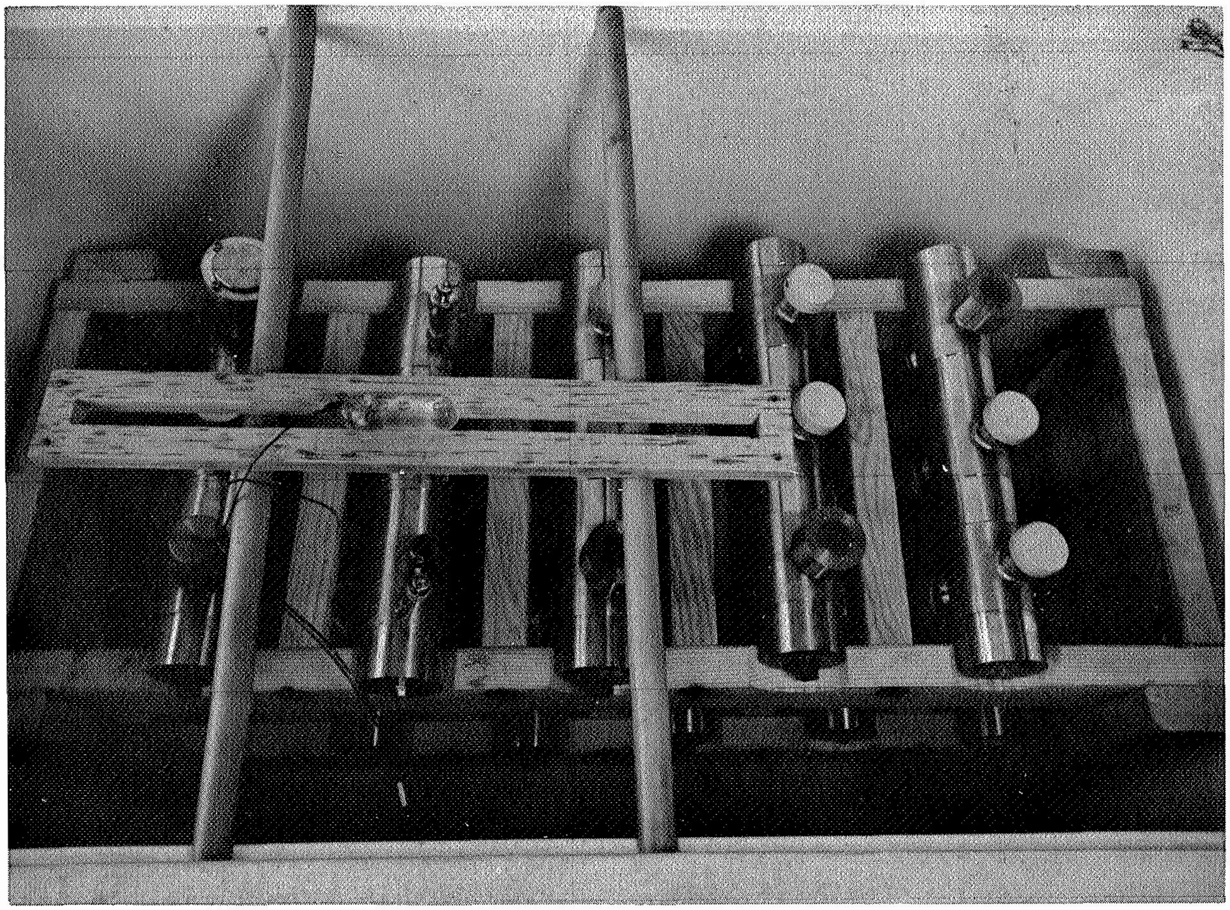
(NOTE: Condition prior to salt fog — same as 304 Stainless Steel)

Figure 30. Salt Fog Test - Burst Disc Cutters



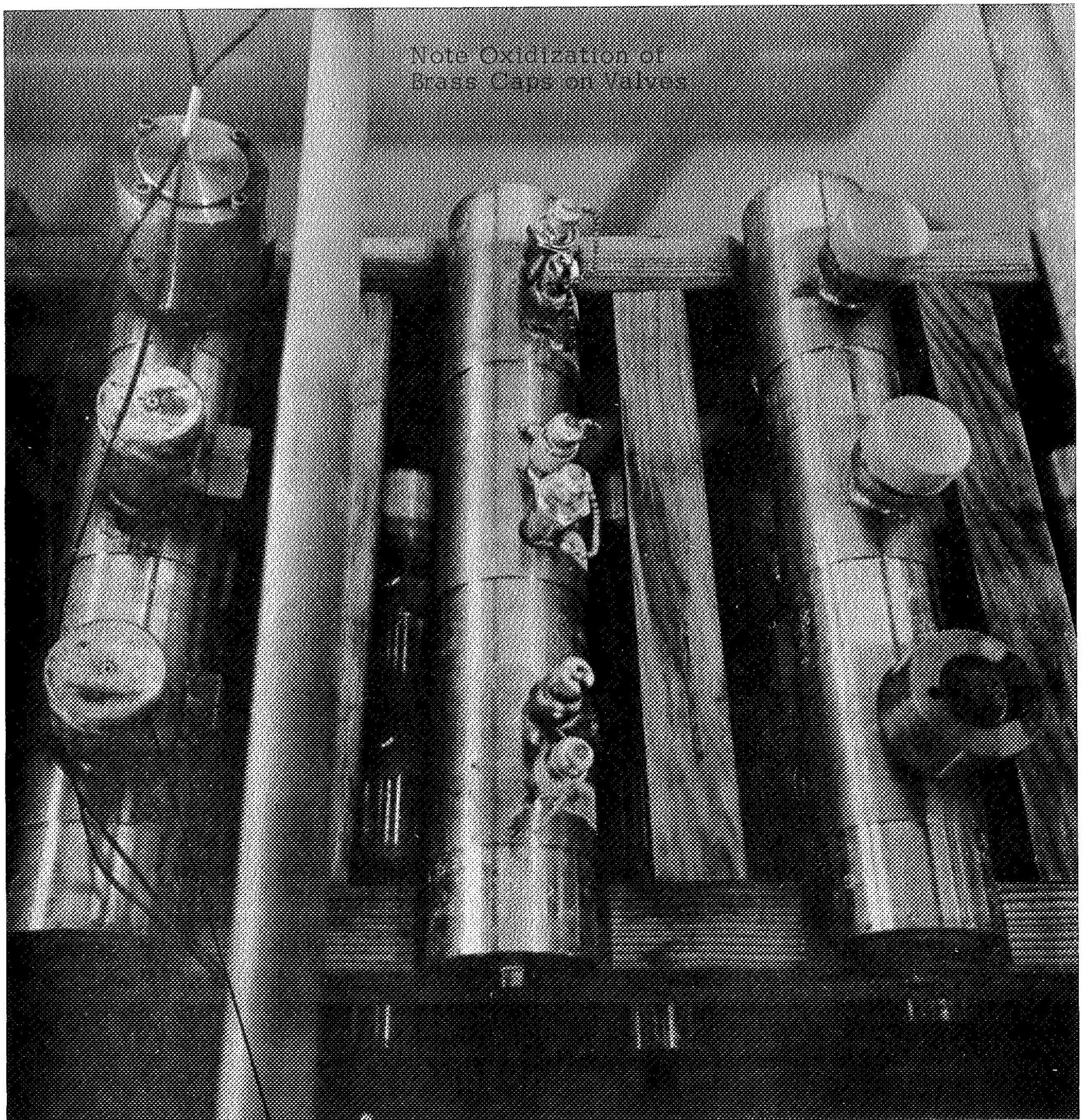
Salt Fog Chamber and Test Manifold Support Rack

Figure 31. Salt Fog Test Manifold Rack



Test Manifolds on Support Rack Inside Salt Fog Chamber
At Start of Salt Fog Test

Figure 32. Salt Fog Test - Burst Disc

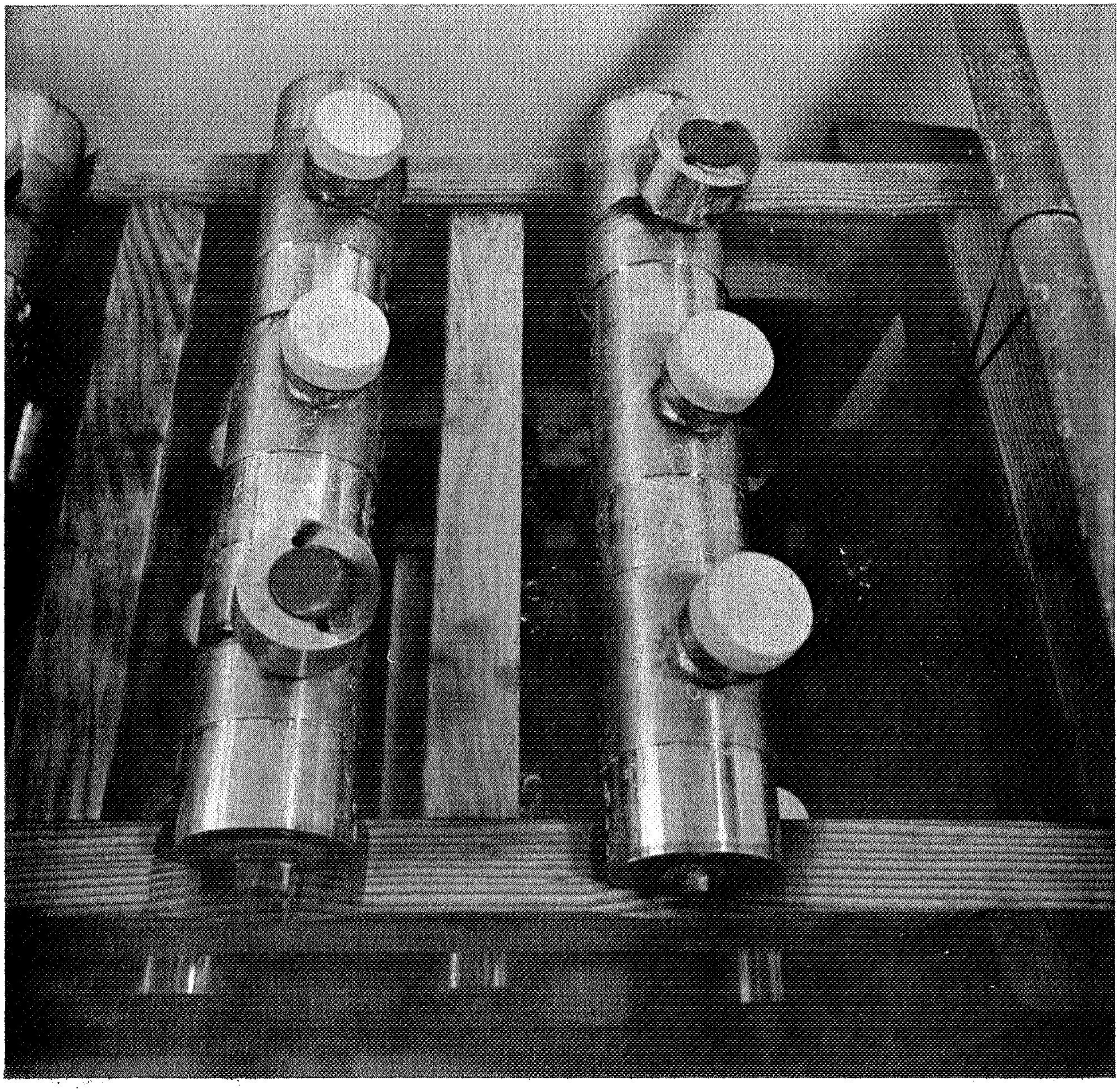


Note 304 Stainless Steel Port Cap Corrosion

Note Drainage From Vacuum Probe Caps

Vacuum Seal Valves, Vacuum Probes, And Burst Discs Following Salt Fog Test

Figure 33. Salt Fog Test - Valves, Probes, Burst Disc

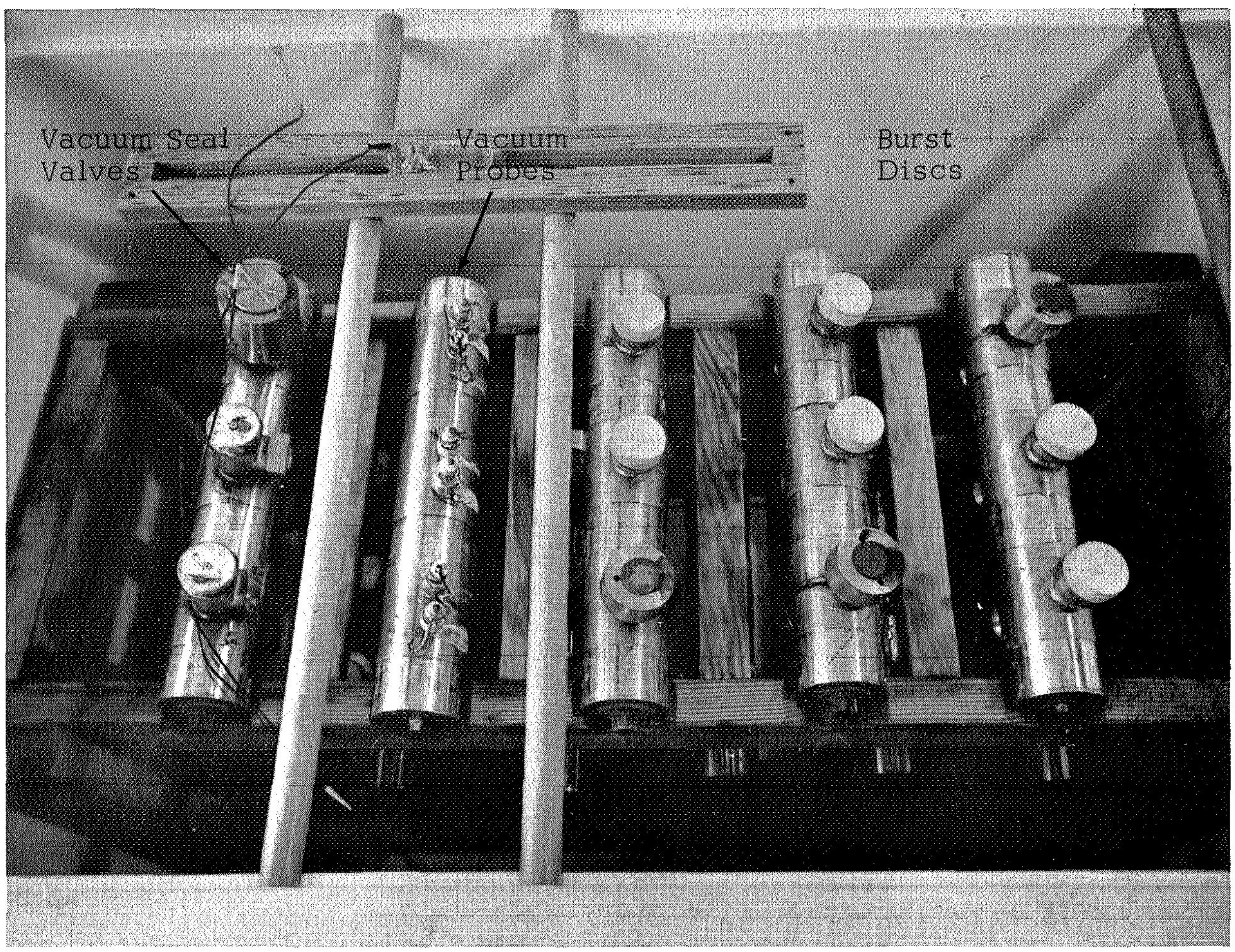


Note Corrosion and Drainage From Interface Weld and Spanner Wrench Holes

Burst Discs After Salt Fog Test

Figure 34. Salt Fog Test - Burst Disc

Specimens Shown Inside of Salt Fog Chamber

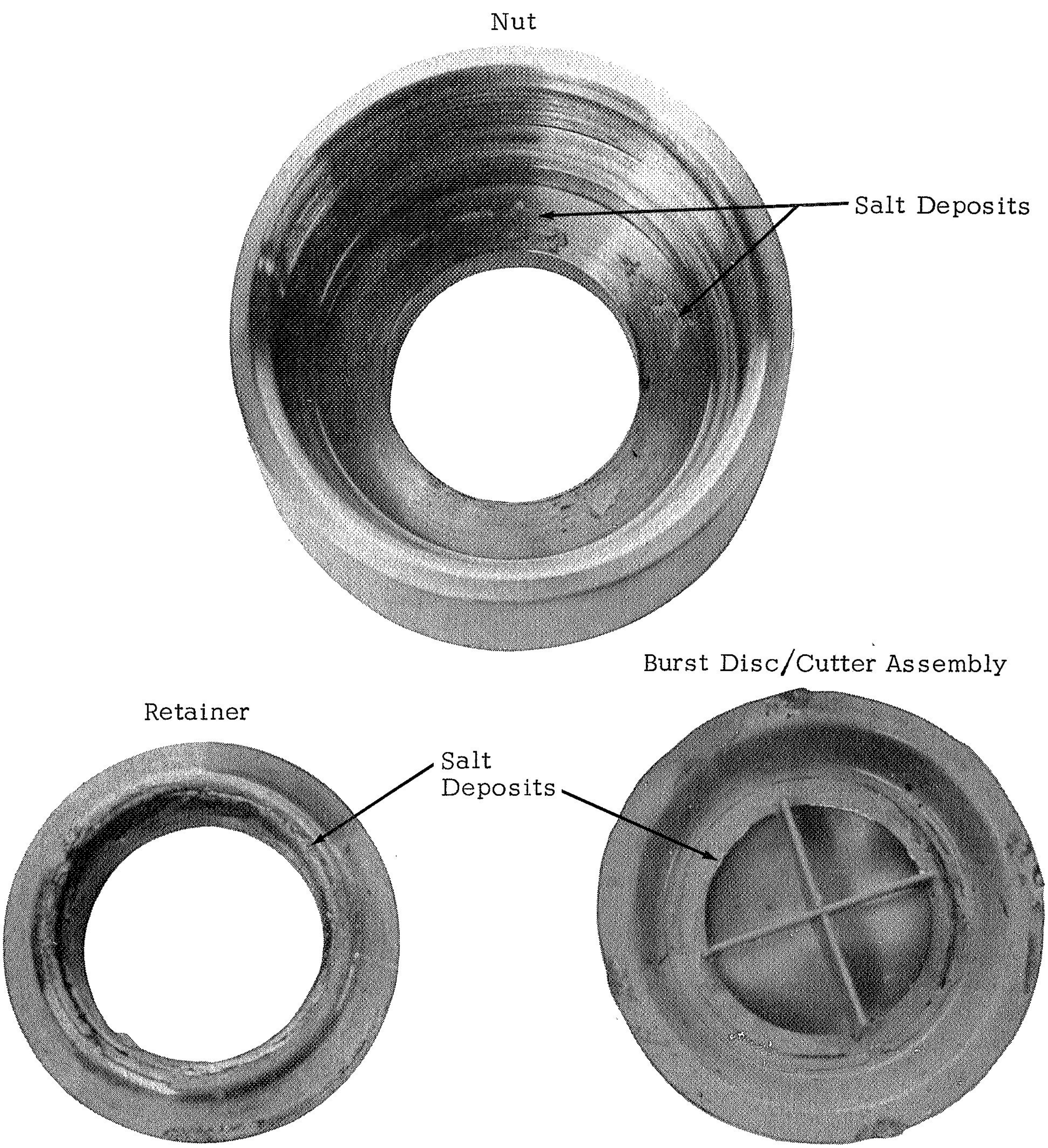


Note Drainage on Vacuum Probe's Manifold From Caps

Note Drainage On Burst Discs From Interface Weld and Spanner Wrench Holes

Test Maniolfds Following Salt Fog Test
(Vacuum Probes, Vacuum Seal Valves, and Burst Discs)

Figure 35. Salt Fog Test - Valves, Probes, Burst Disc

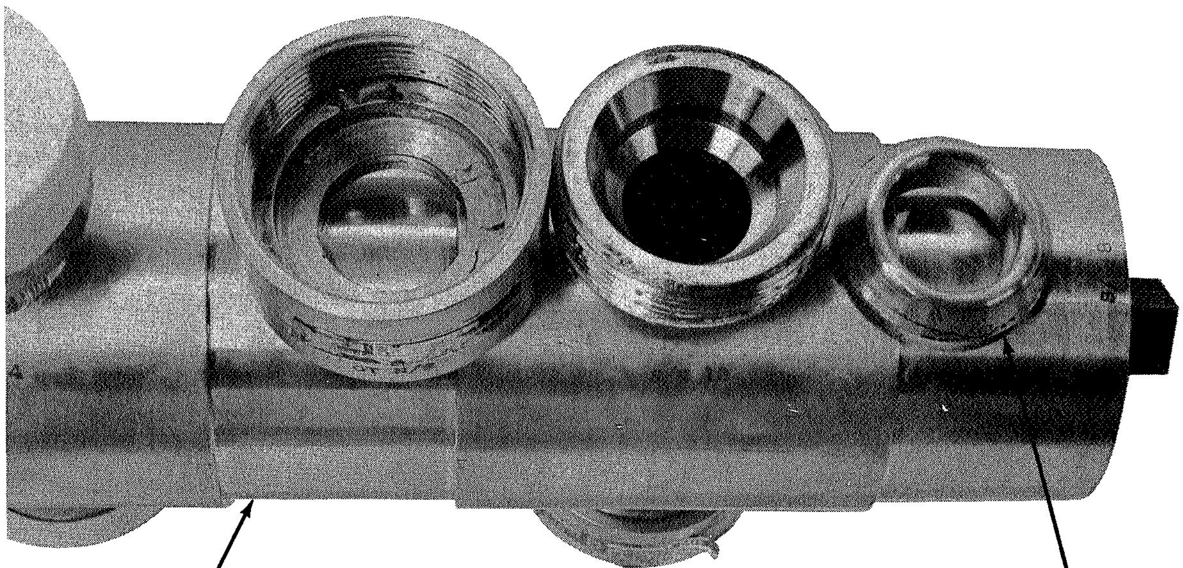


In addition to discolored material, this test sample had salt deposits resulting from leakage through the threads of the Nut.

AMETEK/Calmec Burst Disc After Salt Fog Test

Figure 36. Salt Fog Test - Burst Disc, Calmec

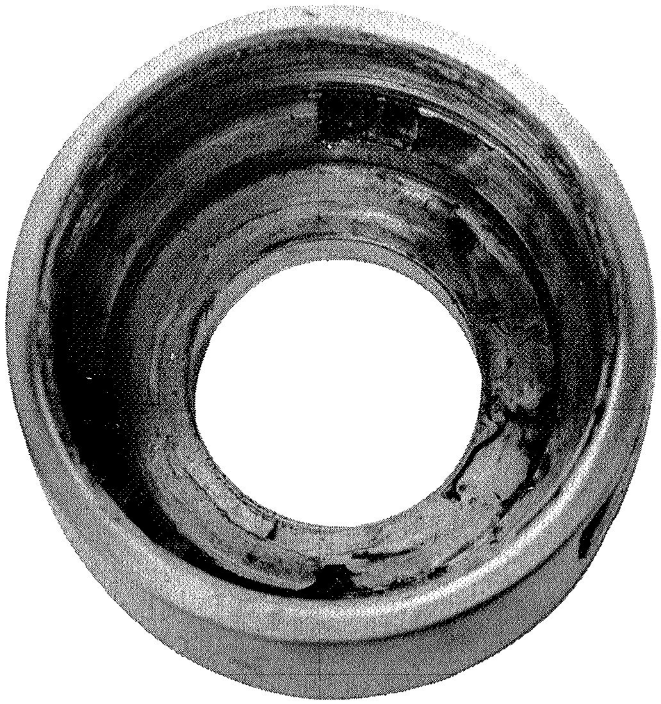
Nut and Retainer are shown next to the Burst Disc Body from which they were removed. The burst disc is not shown. No corrosion of Disc was seen.



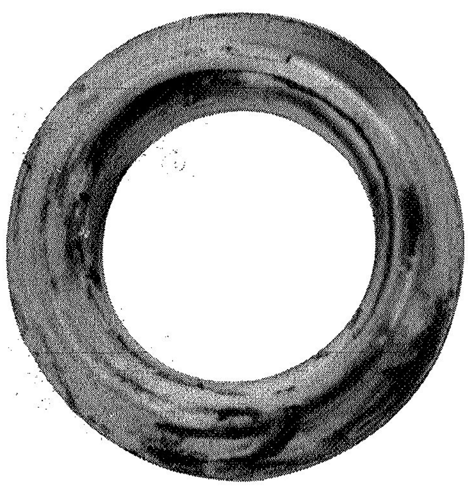
Note how discolored fluid had drained into the disc through the threads of the nut and the burst disc body.

AMETEK/Calmec Burst Disc After Salt Fog Test

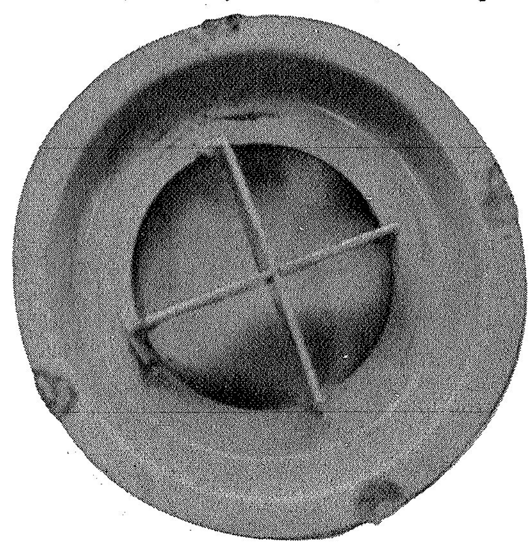
Figure 37. Salt Fog Test - Burst Disc, Calmec



Retainer



Burst Disc/Cutter Assembly



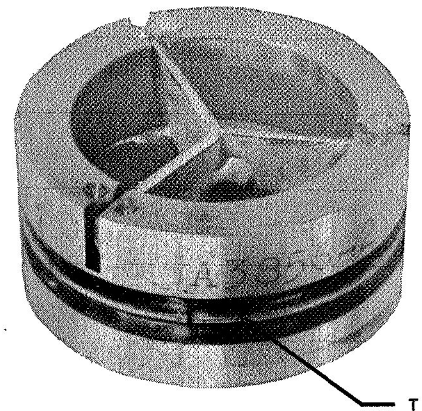
Note build-up of discolored material on the Nut and Retainer. The material had drained from a weld on the outer surfaces of the test manifold into the unit through the threads of the Nut.

No internal corrosion was found on the Burst Disc

AMETEK/Calmec Burst Disc After Salt Fog Test

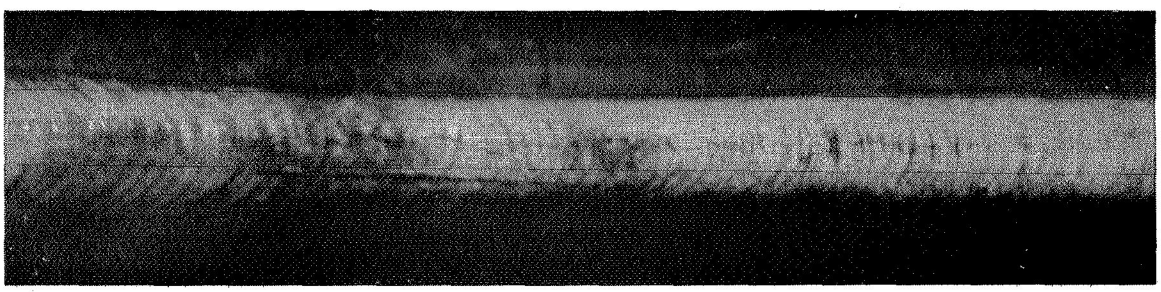
Figure 38. Salt Fog Test - Burst Disc, Calmec

General View of Burst Disc/Cutter Assembly

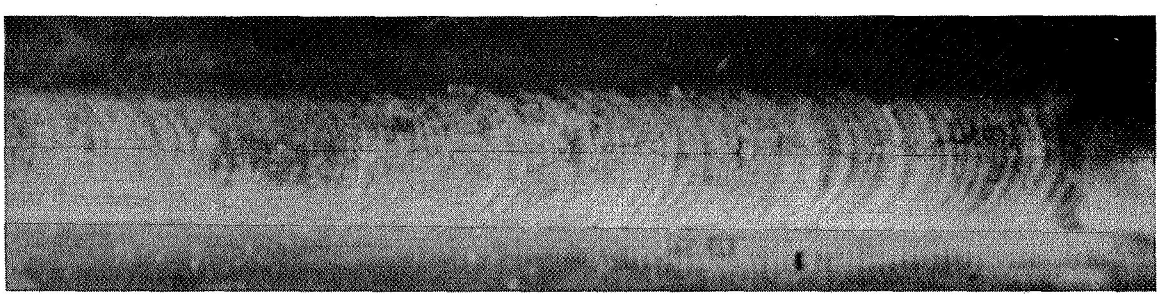


Leakage Occurred From
Weld Crack Caused During
Manufacture of Disc Assembly

30X Magnification of Cracked Area



40X Magnification of Cracked Area



AMETEK/Calmec Burst Disc After Salt Fog Test

Figure 39. Salt Fog Test - Burst Disc, Fike

Salt Fog Test - Burst Disc Assembly

Requirements

The purpose of this test is to subject the entire assembled burst disc (body, burst disc cutter and burst diaphragm) to a salt fog environment.

The test specimens are subjected to 240 hours of exposure in a salt fog atmosphere of 5% salt and 95% water at $95^{\circ}F$ $+ 25^{\circ}F$, $-4^{\circ}F$. Testing is performed with protective covers in place. Following the test, the specimens are allowed to stand until thoroughly dry. The test specimens are photographed at the conclusion of the test.

Procedure

The test specimens were to be placed in the test chamber as shown on Figure 40 and subjected to the salt fog test. The test specimens were to be photographed before and after the test. Following the salt fog test the specimens were to be visually inspected for corrosion. A functional leakage test was performed and all the data recorded.

Test Results

All burst disc assemblies completed salt fog tests. (See Figures 31 & 32). No internal corrosion was found on any of the burst disc specimens. Light corrosion occurred on test fixture/specimen interface welds and spanner wrench holes. (See Figures 33,34 and 35).

Several AMETEK/Calmec disc assemblies that were in an upside-down attitude had discolored water drain into them from the outside through the threads of the body retainer nut. No corrosion resulted from this thread leakage (See Figures 36, 37,38 and 39). The functional leakage test was performed on 30 specimens with one (1) specimen having leakage above the allowable (Fike A3857S/N 3).

Inspection of the specimen indicated a cracked weld (see Figure 39). It was determined that this failure was not the result of the salt fog test but a manufacturing defect. For this reason, the failed replaceable disc assembly was replaced and testing was continued.

Test Data

The following test data sheets and photographs reflect the results of the salt fog test followed by the functional leak test.

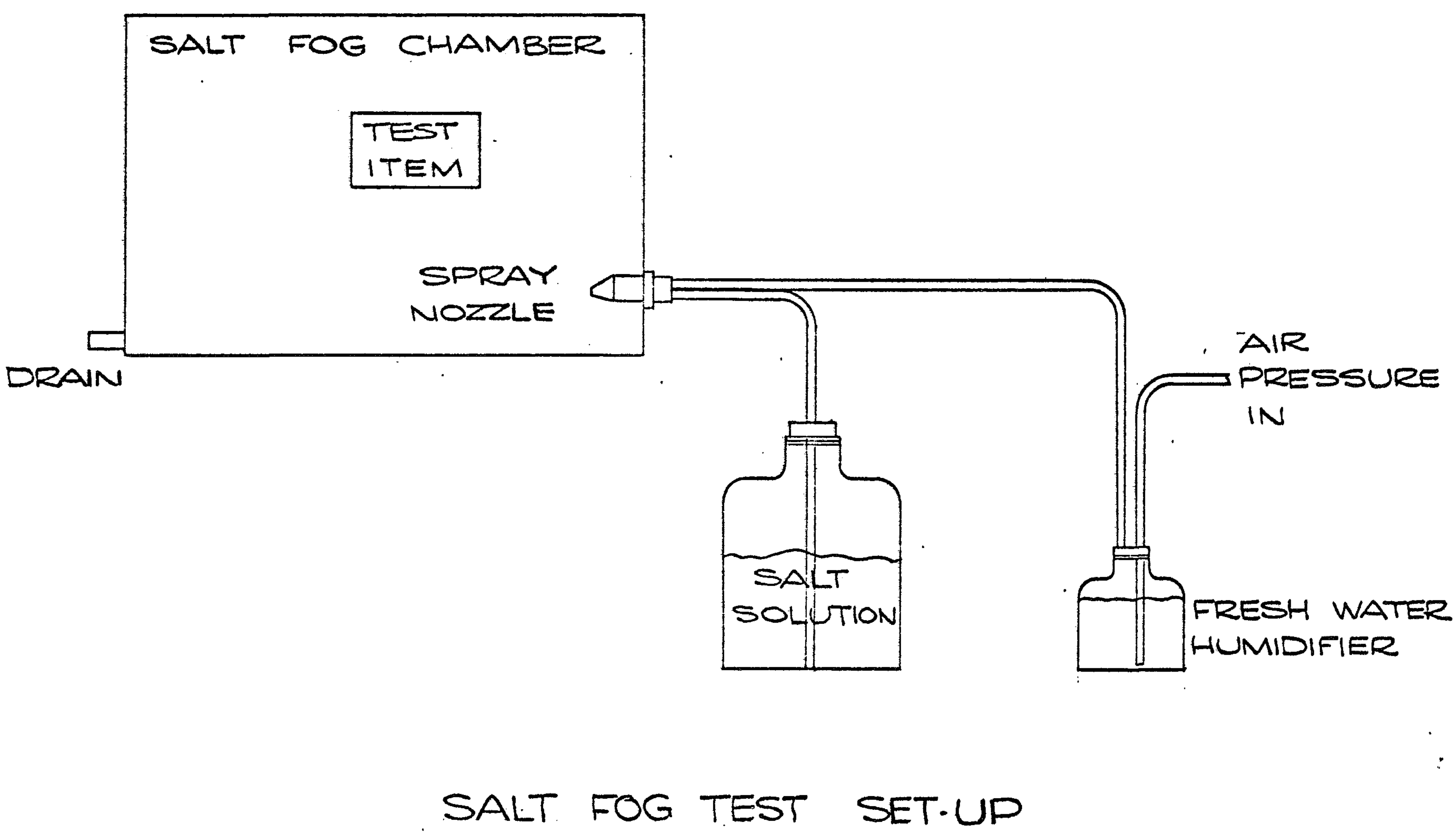


Figure 40. Salt Fog Test Set-Up

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-25-69

Part Name Burst Disc Part Number A 3857-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 9

Remarks

This test was performed following Salt Fog Test (Para. 5.4)

A. Leakage

Leak Rate Before Pressure

Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure

Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician L. McKNIGHT s/s

Test Engineer J. Martins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional — Date of Test: 8-25-69

Part Name: Burst Disc — Part Number: Fike A3857-1

Test Procedure: 8-440087, Para. 5.2 — Part Serial Number: 10

A. Leakage

Leak Rate Before Pressure Test: $< 1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure Test: $<1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure: 20 ± 2 psig

Test Media: GN_2

Duration of Test: 2 min.

Remarks

This test was performed following Salt Fog Test (Para. 5.4)

Unit was repaired with Omniseal SILVAC prior to functional test.

This specimen leaked during proof pressure.

Test Technician: L. McKNIGHT s/s — Test Engineer: J. MARTINEZ s/s

DESIGN VERIFICATION TEST

TEST DATA SHEET

pe of Test: Functional — Date of Test: 8-25-69

rt Name: Burst Disc — Part Number: Fike A 3856-1

st Procedure: 8-440087, Para. 5.2 — Part Serial Number: 3

Leakage

Leak Rate Before Pressure Test $> 1 \times 10^{-5}$ scc/sec

Leak Rate After Pressure Test $< 1 \times 10^{-10}$ scc/sec

Pressure Test

Test Pressure: 20 ± 2 psig

Test Media: GN_2

Duration of Test: 2 Min.

Remarks

This test was performed following Salt Fog Test (Para. 5.4)

Unit leaked above the allowable during Functional Test. Unit was disassembled and inspected for leak location. Leakage resulted from cracked weld at disc assembly.

Disc assembly was replaced and testing to continue. Leakage rate after new disc assembly installed 1×10^{-10} scc/sec.

Leakage rate after pressure test $< 1 \times 10^{-10}$ scc/sec

Test Technician: L. McKnight S/S — Test Engineer: J. Martinez S/S

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-25-69

Part Name Burst Disc Part Number A 3856-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1, 2, 4 - 10

Remarks

This test was performed following Salt Fog Test (Para. 5.4)

A. Leakage

Leak Rate Before Pressure Test $< 1\text{x}10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1\text{x}10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician L. McKNIGHT 5/5

Test Engineer J. Mastins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 8-25-69

Part Name Burst Disc Part Number RDS-106-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks

This test was performed following Salt Fog Test (Para. 5.4)

A. Leakage

Leak Rate Before Pressure

Test $< 1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure

Test $< 1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician L. McKNIGHT S/S

Test Engineer J. Mattina

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Salt Fog — Date of Test: 8-12-69 - 8-22-69

Part Name: Burst Disc — Part Number: As Shown

Test Procedure: 8-480087 — Part Serial Number: As Shown

Test Pressure: AMB — Test Media: 5% Salt Sol. — Duration of Test: 240 Hr

	Manufacturer	Serial Number	Remarks
1.	Calmec RDS-106	1	No corrosion of disc or detrimental effect.
2.	Calmec RDS-106	2	No corrosion of disc or detrimental effect.
3.	Calmec RDS-106	3	No corrosion of disc or detrimental effect.
4.	Calmec RDS-106	4	No corrosion of disc or detrimental effect.
5.	Calmec RDS-106	5	No corrosion of disc or detrimental effect.
6.	Calmec RDS-106	6	No corrosion of disc or detrimental effect.
7.	Calmec RDS-106	7	No corrosion of disc or detrimental effect.
8.	Calmec RDS-106	8	No corrosion of disc or detrimental effect.
9.	Calmec RDS-106	9	No corrosion of disc or detrimental effect.
10.	Calmec RDS-106	10	No corrosion of disc or detrimental effect.
11.	Fike A 3856-1	1	No corrosion of disc or detrimental effect.
12.	Fike A 3856-1	2	No corrosion of disc or detrimental effect.
13.	Fike A 3856-1	3	No corrosion of disc or detrimental effect.
14.	Fike A 3856-1	4	No corrosion of disc or detrimental effect.
15.	Fike A 3856-1	5	No corrosion of disc or detrimental effect.
16.	Fike A 3856-1	6	No corrosion of disc or detrimental effect.
17.	Fike A 3856-1	7	No corrosion of disc or detrimental effect.
18.	Fike A 3856-1	8	No corrosion of disc or detrimental effect.
19.	Fike A 3856-1	9	No corrosion of disc or detrimental effect.
20.	Fike A 3856-1	10	No corrosion of disc or detrimental effect.
21.	Fike A 3857-1	1	No corrosion of disc or detrimental effect.
22.	Fike A 3857-1	2	No corrosion of disc or detrimental effect.
23.	Fike A 3857-1	3	No corrosion of disc or detrimental effect.
24.	Fike A 3857-1	4	No corrosion of disc or detrimental effect.

Test Technician: L. McKnight s/s — Test Engineer: T. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Salt Fog — Date of Test: 8-12-69 - 8-22-69

Part Name: Burst Disc — Part Number: As Shown

Test Procedure: 8-480087 — Part Serial Number: As Shown

Test Pressure: AMB — Test Media: 5% Salt Sol. — Duration of Test: 240 Hrs.

	Manufacturer	Serial Number	Remarks
1.	Fike A 3857-1	5	No Corrosion of Disc or Detrimental Effect.
2.	Fike A 3857-1	6	No Corrosion of Disc or Detrimental Effect.
3.	Fike A 3857-1	7	No Corrosion of Disc or Detrimental Effect.
4.	Fike A 3857-1	8	No Corrosion of Disc or Detrimental Effect.
5.	Fike A 3857-1	9	No Corrosion of Disc or Detrimental Effect.
6.	Fike A 3857-1	10	No Corrosion of Disc or Detrimental Effect.
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			
21.			
22.			
23.			
24.			

Test Technician L. McKNIGHT 5/5 Test Engineer J. Martine

1.2.3.6.5 Sand and Dust Test

Requirements

The sand and dust test was performed to determine the resistance of the test item to blowing fine sand and dust particles.

The test was conducted in accordance with Section 16 of KSC-STD-164D. The test item was placed in the test chamber as shown in Figure 41 and in accordance with Paragraph 4.4.1 of KSC-STD-164D. The test item was exposed to a sand and dust environment with a sand to air ratio of 0.1 to 0.25 grams per cubic foot with an air velocity of from 100 to 500 feet per minute. The test item was exposed to this environment for two hours at 77 ±2°F. The temperature was then raised to 160 ±2°F under the same test conditions for two hours. At the conclusion of the sand and dust test the test item was returned to room ambient conditions.

The test item was disassembled and assembled three times during the length of the test. Each re-assembly was followed by a functional test and the test data recorded.

Procedure

The test chamber ambient temperature was continuously recorded. The sand to air ratio was measured at the beginning and conclusion of the test and every two hours during the test. The test item was photographed at the conclusion of the test.

The functional test was performed and test data recorded as specified.

Results

Disassembly operations on the two replaceable burst disc types were made following the first hour, the second hour, and upon completion of the test. Following each disassembly operation, the test specimens were functionally leak tested. Disassembly and assembly operations indicate that this hardware is field maintainable if precautions are taken to keep sealing surfaces clean. The AMETEK/Calmec units are easier to assemble than the Fike unit because of the high torque required to seal the Fike unit. After one installation, the Fike teflon seal cannot be re-used because of distortion (cold flow). No leakage was detected during functional testing after each disassembly and following sand and dust test.

The following data sheets reflect the information gathered by tests performed at Ogden Technology Laboratories, Monterey Park, California.

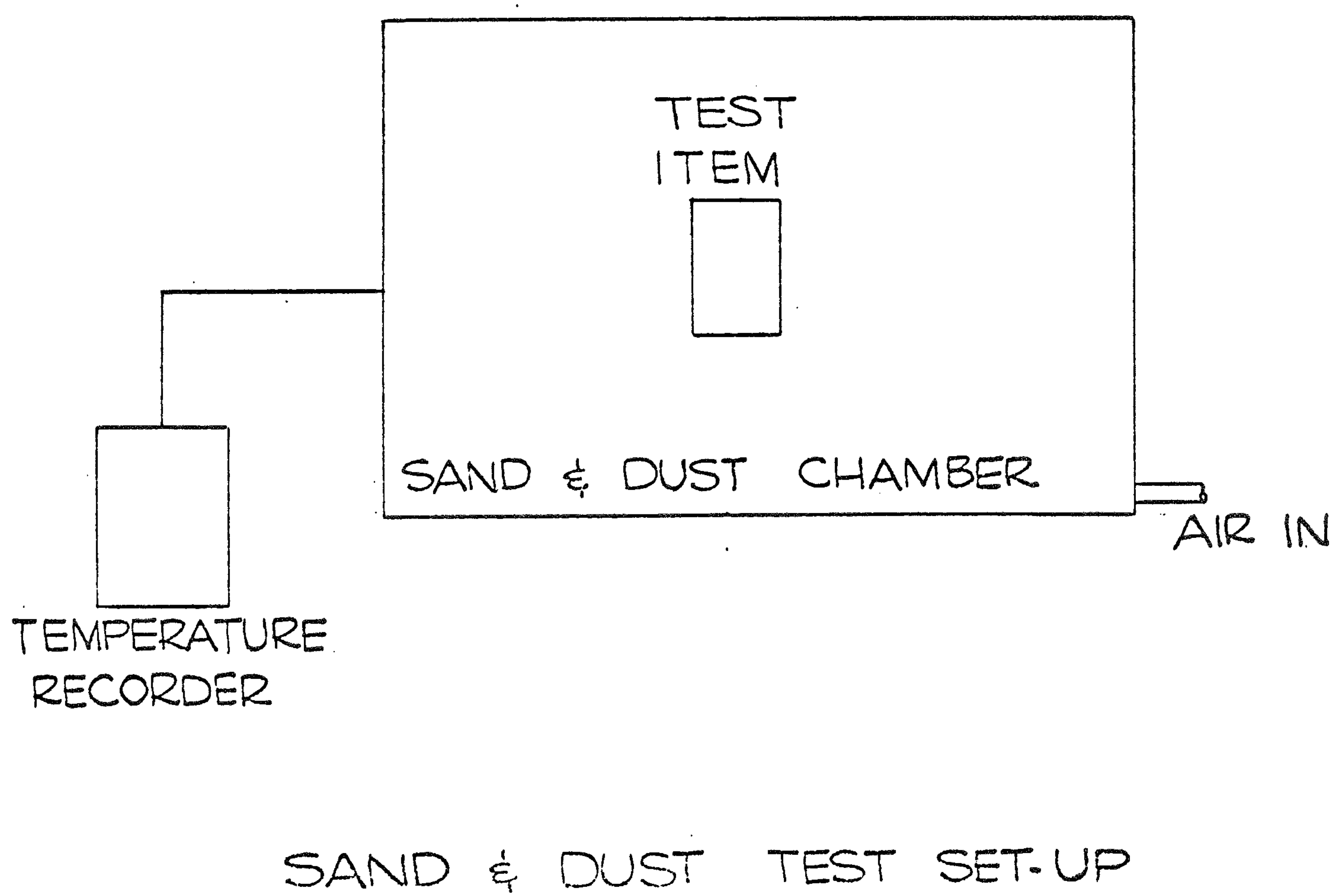


Figure 41. Sand and Dust Test Set-Up

OGDEN TECHNOLOGY LABORATORIES, INC.
Subsidiary of Ogden Corporation

573 MONTEREY PASS ROAD, MONTEREY PARK, CALIFORNIA 91754
TELEPHONE: 213 - 289-4425 TWX: 213 - 299-3123

September 3, 1969

MONTEREY PARK DIVISION REPORT NUMBER M-69477
Ametek/Straza Purchase Order Number 73947

A. TEST: Sand & Dust Test

B. SAMPLE: (2) Vacuum Probes, (3) Vacuum Seal Valves, (5) Burst Discs

C. SPECIFICATION: Ametek/Straza Test Document No. 8-480090, 8-48009, 8-480087

D. RESULTS: This is to certify that the samples were subjected to the Sand & Dust Test according to the above Specifications and the following results recorded:

The samples met the requirements of the Sand & Dust Test. See Data Sheet for Performance Tests during the Sand & Dust Test.

OGDEN TECHNOLOGY LABORATORIES, INC.
Monterey Park Division

R. Short

R. Short
Operations Manager

Subscribed and sworn to before me this 3rd day of September 1969.

OFFICIAL SEAL
JUDITH L. PITTS
NOTARY PUBLIC-CALIFORNIA
LOS ANGELES COUNTY
My Commission Expires Feb. 24, 1973

Judith L. Pitts

Judith L. Pitts, Notary Public in and for the County of Los Angeles.
State of California.

A. Darco

OGDEN
0410

A. Darco
Quality Assurance Manager

Helmut A. Stegmeier

Helmut A. Stegmeier
Project Engineer

rv

EQUIPMENT LIST

Apparatus	Calibration Date
OTL Sand & Dust Chamber .1 to .25 9/ft3 Control No.-2056	One Shot
General Radio Strobotac Model 631-BL 600 - 3600 rpm Control No. 5299	6 months Due 9-5-69
Leeds & Northrup Potentiometer Model 8369 .2% Accuracy, -100°F +500°F. Control No. 1016	12 months Due 4-4-70
Hygrodynamics Hygrometer Model 15-3001 0-100%, 0-140°F. Control No. 2194	12 months Due 7-8-70
Ashcroft Test Gauge Model 1279, Accuracy ± .25%, 0-30psig, Control No. 991	3 months Due 10-7-69
Minerva Stopwatch Accuracy 1%, 0-30psig, Control No. 415	6 months Due 2-18-70
CEC Leak Detector Model 24-120 Accuracy ± .25%, 1 x 10^{-10} cc/sec. 0-100,000 units Control No. 1465	Before Use

OGDEN TECHNOLOGY LABORATORIES, INC.

SAND AND DUST DATA SHEET

Date 8-29-69 Job Number M69477

Customer AMETEK/Straza Page Number

Specimen Burst Discs Part No. Serial No. As Noted

Specification No. 8-480087 Para. No.

Preparation of Specimen(s) Five (5) Tube Assemblies

Protective Covering on Non-Tested Parts N/A

Vents, Ports, Connectors, etc., Capped: Yes X No Remarks Discs Capped

Support Method Five (5) Units Horizontal

Orientation of Specimen(s)

Chamber Controls: Sand and Dust Density 0.1 to 0.25 grams/cubic foot

Wind Velocity 100 to 500 feet/minute

Relative Humidity <30 percent

Temperature 77 °F

Elapsed Time (hours)	Sand and Dust Density (grams/cu.ft.)	Air Velocity (ft/minute)	Temperature (°F)	Relative Humidity (%)
10:20	0.25	375	76	<30
*11:20	0.25	375	78	
16:30	0.25	375	78	<30
*17:30	0.25	375	78	
12:10	0.25	375	158	<30
14:10	0.25	375	159	

REMARKS: None

*Interruptions during test (Explain): Disassembly and assembly of Burst Disc performed at 11:20 and 9:00, 9-2-69.

Results: Damage or Deformation: Yes No X (Explain above)

Photograph taken: Yes X No

Test Technician *Phil Paredes* Test Engineer *R.A. Stegmeiller s/s*

Inspector (Customer or U.S. Gov't) *Joseph Martin*

A. Dacco s/s

Q.A. Mgr. Signature

Report Number M-69477

Date Started: 8-29-69		TEST DATA	Performed By: P. Paredes / Kunst s/s
Date Completed: 8-29-69		Specimen Description: Burst Disc	OTL Q.A. H.A. Stegmeither s/s
Temp: 80°F	Humidity: 46%	Test: Maintenance Verification	Cust. Insp. J. Martinez
P/N: A 3856-1 RDS-106-1 A 3857-1		Customer: AMETEK/Straza	Gov't. Insp. N/A
Spec: 8-480087		Para.: S/N: Noted	J/N: M69477

Manifold S/N	Maintenance Performed by Mr. Martinez — Under Surveillance of Phil Paredes. After 1st Hour of Sand and Dust
7	Discs assembly S/N 8 shall not be re-opened per Mr. Martinez's request — checked two Calmecs.
6	Discs assembly S/N 9 checked — checked two Calmecs — Replaced Teflon seal in S/N 9 Fike A 3856-1
4	Two Calmecs checked — No. 2 Calmec shall not be re-opened — S/N 7 Fike checked — Calmec No. 1 shall not be re-opened
8	Checked Calmec S/N 9 — Fike S/N 10 checked — Noted large scratch on inner seal surface. Calmec No. 10 checked — Shall not be re-opened.
5	Calmec No. 4 (capped No. 3) checked. Fike No. 1 checked. Calmec No. 3 (capped No. 4) checked.
	Calmec Torque — 150 in./lbs. Fike Torque — 600 in./lbs.

Date Started: 8-29-69	TEST DATA	Performed By: H.A. Stegmeier 5/5
Date Completed: 8-29-69	Specimen Description: Burst Disc	OTL Q.A. H.A. Stegmeier 5/5
Temp: AMB / Humidity: AMB	Test: Sand and Dust	Cust. Insp.. T. Mastine
P/N: A 3856-1 RDS-106 A 3857-1	Customer: AMETEK/Straza	Gov't. Insp. N/A
Spec: 8-480087	Para.:. S/N:	J/N: M69477

Manifold S/N	After 1st Hour of Sand and Dust and Disassembly and Assembly of Burst Disc
4	Leakage <1 x 10^{-10} scc/sec He
	Pressure 18 psig GN_2 — No Effect
	Leakage <1 x 10^{-10} scc/sec He
	(Following Pressure)
5	S/A
6	S/A
7	S/A
8	S/A

Report Number M-69488

Date Started: 9-2-69	TEST DATA	Performed By: T. Martine / Kunst
Date Completed: 9-2-69	Specimen Description: Burst Discs	OTL Q.A. H.A. Steigmeier - SK
Temp: 80°F Humidity: 46%	Test: Assembly & Disassembly	Cust. Insp. T. Martine
P/N: A 3856-1 RDS-106 A 3857-1	Customer: AMETEK/Straza	Gov't. Insp. N/A
Spec: 8-480087	Para.: S/N: Noted	J/N: M69477

Manifold S/N	Maintenance — After 2nd Hour of Sand and Dust Disassembly and Assembly of Burst Discs
7	Disc Assembly S/N 3 (A 3856-1)
	2 Calmecs RDS-106 S/N 7 & 8
6	Disc Assembly S/N 2 (A 3856-1)
	2 Calmec RDS-106 S/N 5 & 6
5	Disc Assembly S/N 5 (A 3856-1)
	2 Calmec RDS-106 S/N 3 & 4
8	Disc Assembly S/N 4 (A 3856-1)
	2 Calmec RDS-106 S/N 9 & 10
	(Calmec Disc Tack Welds Loose — S/N 10)
4	Disc Assembly S/N 6 (A 3856-1)
	2 Calmec RDS-106 S/N 1 & 2

Date Started: 9-2-69		TEST DATA	Performed By: H. A. Stegmeier s/s
Date Completed: 9-2-69		Specimen Description: Burst Disc	OTL Q.A. H. A. Stegmeier s/s
Temp: AMB	Humidity: AMB	Test: Sand and Dust	Cust. Insp. T. Martinez
P/N: A 3856-1 RDS-106 A 3857-1		Customer:	Gov't. Insp. N/A
Spec: 8-480087		Para.: S/N:	J/N: M69477

Manifold S/N	After 2nd Hour of Sand and Dust and Disassembly and Assembly of Specimens
4	Leakage <1 x 10^{-10} scc/sec
	Pressure 18 psig GN_2 — No Effect
	Leakage <1 x 10^{-10} scc/sec
	(Following Pressure)
5	S/A
6	S/A
7	S/A
8	S/A

Date Started: 9-2-69	TEST DATA	Performed By: T. Masting / Kunst s/s
Date Completed: 9-2-69	Specimen Description: Burst Disc	OTL Q.A.: H. Steegmeither s/s
Temp: AMB / Humidity: AMB	Test: Sand and Dust	Cust. Insp.: T. Masting
P/N:	Customer: AMETEK/Straza	Gov't. Insp.: N/A
Spec: 8-480087	Para.: S/N:	J/N: M69477

Manifold S/N	Disassembly and Assembly of Burst Disc After 4 Hours of Sand and Dust	
4	Fike A 3856-1	S/N 7
	Calmec RDS-106	2
5	Fike A 3856-1	S/N 1
	Calmec RDS-106	4
6	Fike A 3856-1	S/N 2
	Calmec RDS-106	5
7	Fike A 3856-1	S/N 8
	Calmec RDS-106	8
8	Fike A 3856-1	S/N 10
	Calmec RDS-106-1	9
	NOTE: One (1) specimen of each was functionally tested without disassembly to determine effects of high temperature Sand and Dust test (see Functional Test Data Sheet)	

Date Started: 9-2-69	TEST DATA	Performed By: H.A. Stegmeiher S/S
Date Completed: 9-2-69	Specimen Description: Burst Discs	OTL Q.A. H.A. Stegmeiher S/S
Temp: AMB — Humidity: AMB	Test: Sand and Dust	Cust. Insp. J. Martinez
P/N:	Customer: AMETEK/Straza	Gov't. Insp. N/A
Spec: 8-480089	Para.: S/N:	J/N: M69477

Manifold S/N	Functional Test — Following Sand and Dust		
	RDS-106-1	S/N 1	Leakage <1 x 10^{-10} scc/sec He
		2	Pressure 18 psig — 2 min.
		3	Leakage <1 x 10^{-10} scc/sec He
		4	
		5	
		6	
		7	
		8	
		9	
	RDS-106-1	S/N 10	
	Fike A 3856-1	S/N 1	
		2	
		3	
		4	
		5	
		6	
		7	
		8	
		9	
	Fike A 3856-1	S/N 10	
	Fike A 3857-1	S/N 1	
		2	
		3	
		4	
		5	
		6	
		7	
		8	Leakage <1 x 10^{-10} scc/sec He
		9	Pressure 18 psig — 2 min.
	Fike A 3857-1	S/N 10	Leakage <1 x 10^{-10} scc/sec He

Report Number M-69488

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional

Date of Test 9-3-69

Part Name Burst Disc

Part Number A 3857-1

Test Procedure 8-440087, Para 5.2

Part Serial Number 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test performed after Sand and Dust test.

Test Technician L. McKNIGHT s/s

Test Engineer J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 9-3-69

Part Name Burst Disc Part Number A 3856-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks

This test performed after Sand and Dust test.

A. Leakage

Leak Rate Before Pressure

Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure

Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician L. McKnight 5/5

Test Engineer J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 9-3-69

Part Name Burst Disc Part Number RDS-106-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks

This test performed after Sand and Dust test.

A. Leakage

Leak Rate Before Pressure Test $< 1\times10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1\times10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician L. McKNIGHT 5/5

Test Engineer J. Martins

1.2.3.6.6 Thermal Shock

Requirements

The thermal shock test was conducted to evaluate the test item and protective cap material under the most severe high temperature conditions expected due to the blast of a launch vehicle during lift-off.

Procedure

A flame source having the minimum capability of $1400^{\circ}F$ was to be mounted in a fixed position (See Figure 44). The distance from the flame source at which the temperature of $1400^{\circ}F$ was to be marked. The test item was then to be exposed to the flame at this point for a period of ten (10) seconds.

This test was to be performed first on the side of all burst discs. Following this test, one (1) specimen was to be capped with the protective cover material (Silicone Silastic 55 from Dow Corning) and the flame directed first on the side and then on the top.

Test Results - Burst Discs

Each burst disc assembly completed thermal shock with no visible defects. Functional leak tests showed no detectable leakage of any specimen. (See Figure 42)

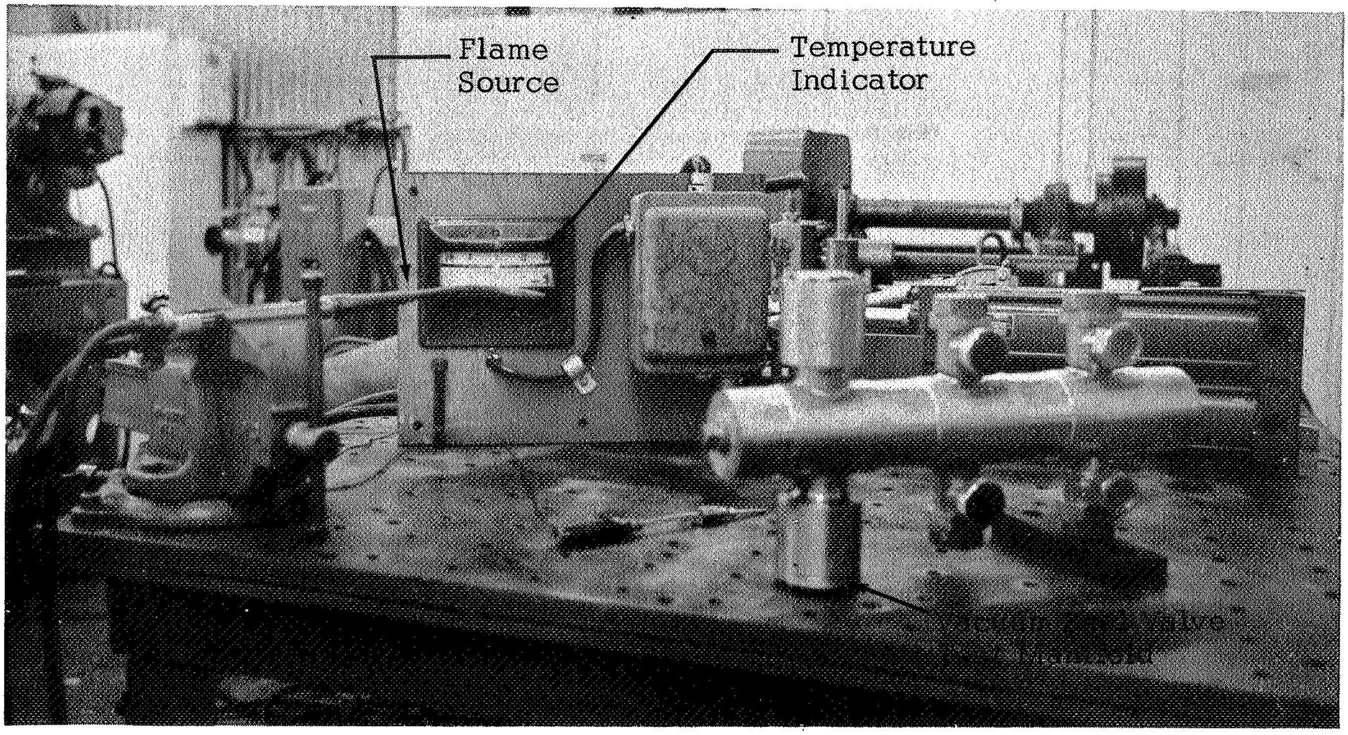
When the test specimens had returned to room ambient temperature, they were photographed in the test position and visually inspected. Visible defects as the result of the test, were recorded. The burst discs were then functionally leak tested and the data recorded.

Test Results - Silicone (Protective Material

The smooth top surface showed no defect after test. Slight flaming occurred on the rougher surface of the side which appeared to be the burning-off of surface impurities (probably the mold release agent residue). An examination of this area revealed slight "checking" of the surface with no deep cracks. Figure 43 shows the protective cap after flame testing was completed.

Test Data

The following test data sheets reflect the results of the test and functional leak test which followed.



Thermal Shock Test Setup

Thermal Shock Test Setup

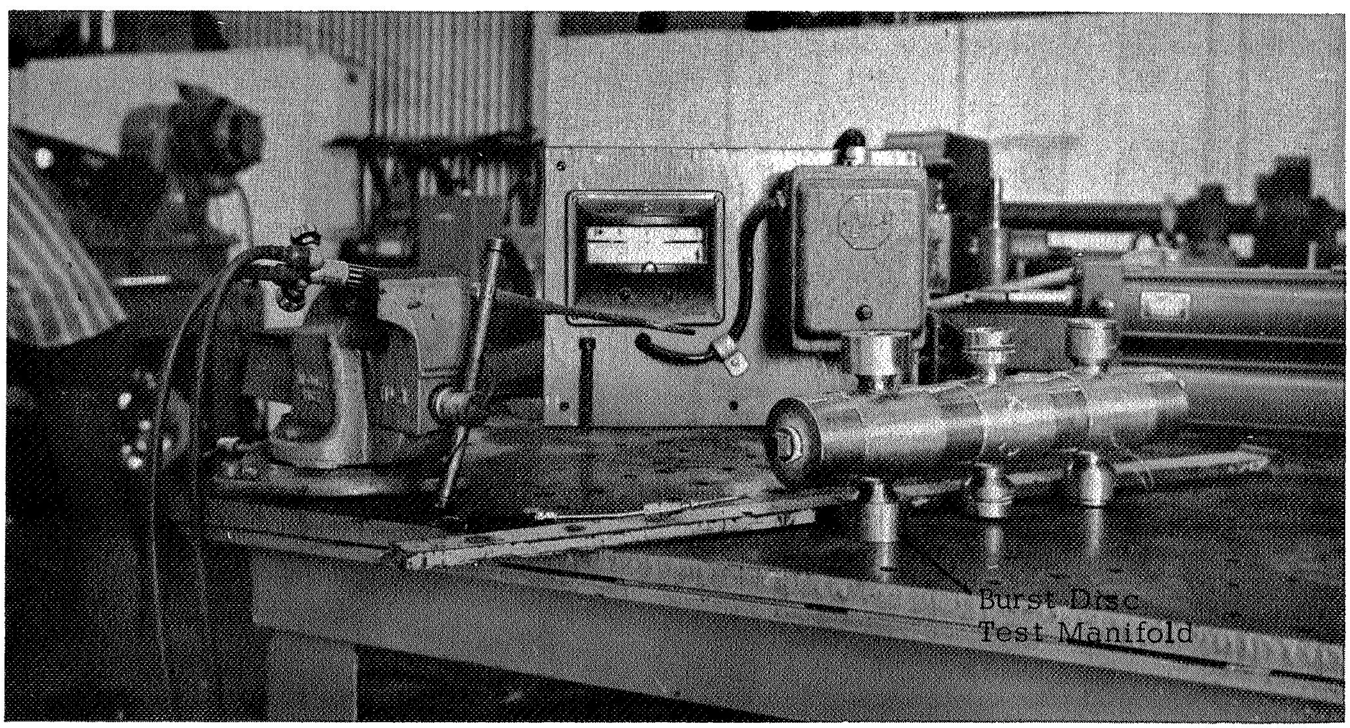
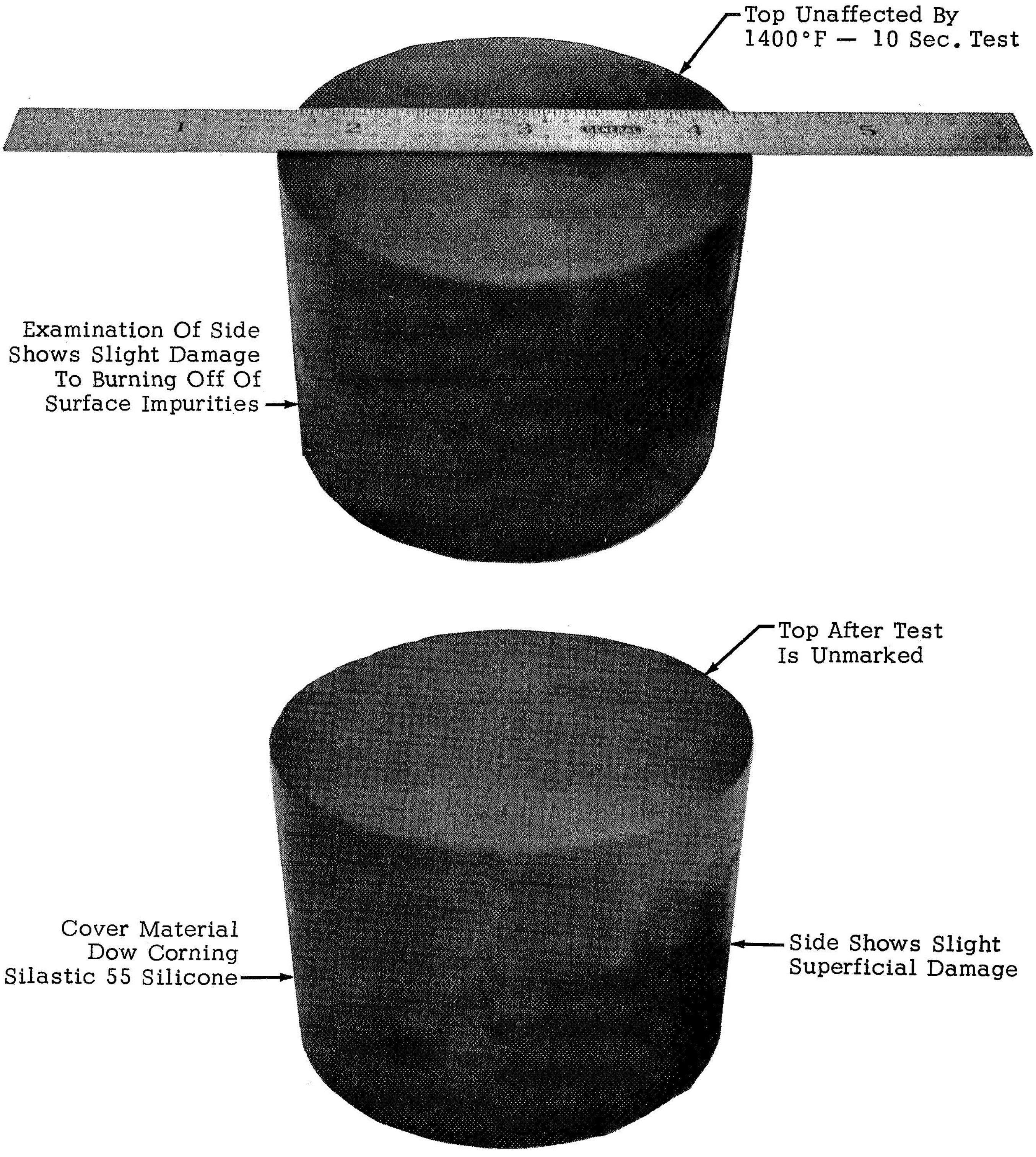


Figure 42. Thermal Shock Test Set-Up



Burst Disc Protective Cover After Thermal Shock Test (1400° F — 10 Sec.)

Figure 43. Thermal Shock Test - Protective Cover

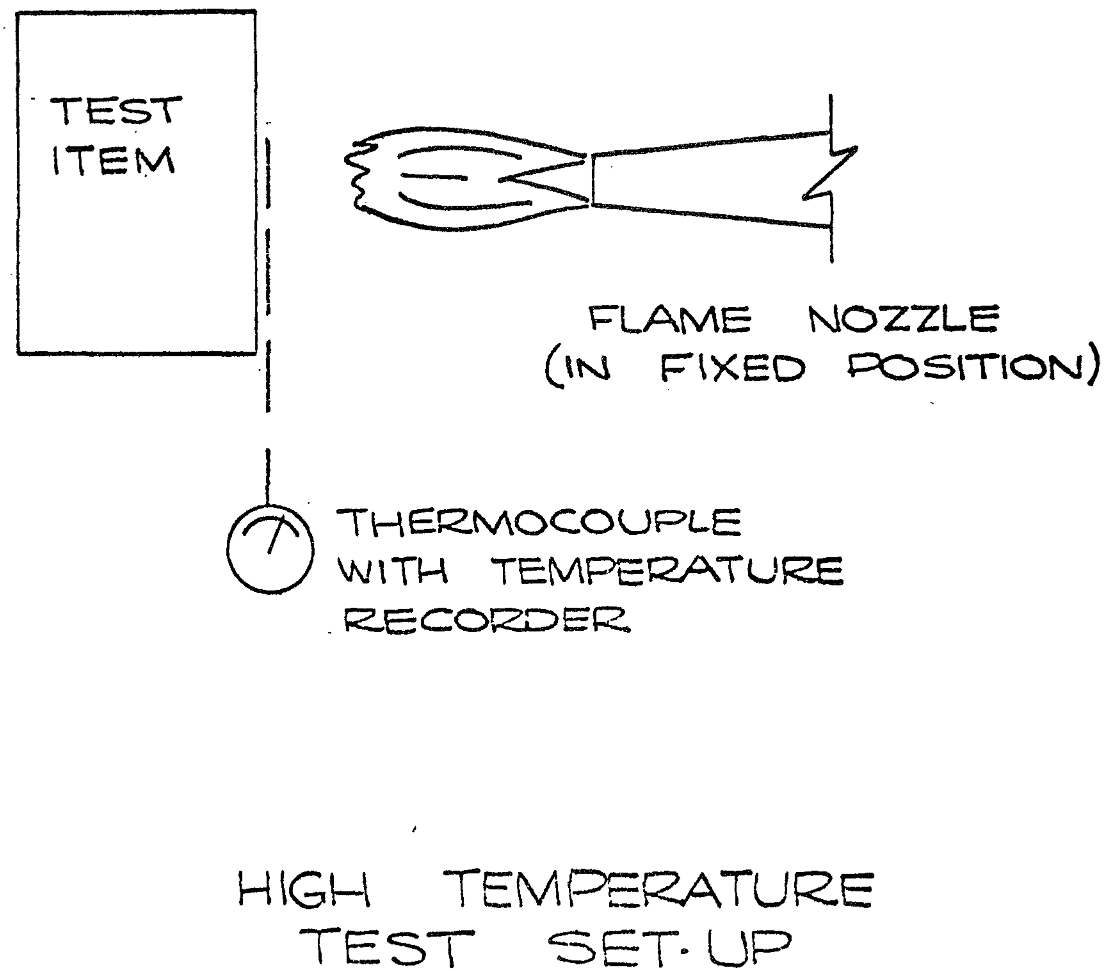


Figure 44. High Temperature Test Set-Up

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Thermal Shock | Date of Test: 10-7-69

Part Name: Burst Disc | Part Number: As Shown

Test Procedure: 8-480087 | Part Serial Number: As Shown

Test Pressure: N/A | Test Media: Flame 1400°F | Duration of Test: 10 sec.

Manufacturer	Serial Number	Remarks
1. Calmec RDS-106	1	No visible damage
2. Calmec RDS-106	2	No visible damage
3. Calmec RDS-106	3	No visible damage
4. Calmec RDS-106	4	No visible damage
5. Calmec RDS-106	5	No visible damage
6. Calmec RDS-106	6	No visible damage
7. Calmec RDS-106	7	No visible damage
8. Calmec RDS-106	8	No visible damage
9. Calmec RDS-106	9	No visible damage
10. Calmec RDS-106	10	No visible damage
11. Fike A 3856-1	1	No visible damage
12. Fike A 3856-1	2	No visible damage
13. Fike A 3856-1	3	No visible damage
14. Fike A 3856-1	4	No visible damage
15. Fike A 3856-1	5	No visible damage
16. Fike A 3856-1	6	No visible damage
17. Fike A 3856-1	7	No visible damage
18. Fike A 3856-1	8	No visible damage
19. Fike A 3856-1	9	No visible damage
20. Fike A 3856-1	10	No visible damage
21. Fike A 3857-1	1	No visible damage
22. Fike A 3857-1	2	No visible damage
23. Fike A 3857-1	3	No visible damage
24.		

Test Technician: J.E. Aberly S/S | Test Engineer: J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Thermal Shock — Date of Test: 10-7-69

Part Name: Burst Disc — Part Number: As Shown

Test Procedure: 8-480087 — Part Serial Number: As Shown

Test Pressure: N/A — Test Media: Flame 1400°F — Duration of Test: 10 sec.

	Manufacturer	Serial Number	Remarks
1.	Fike A 3857-1	4	No visible damage
2.	Fike A 3857-1	5	No visible damage
3.	Fike A 3857-1	6	No visible damage
4.	Fike A 3857-1	7	No visible damage
5.	Fike A 3857-1	8	No visible damage
6.	Fike A 3857-1	9	No visible damage
7.	Fike A 3857-1	10	No visible damage
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			
21.			
22.			
23.			
24.			

Test Technician: J. CPAERLY s/s — Test Engineer: J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Thermal Shock   Date of Test: 10-7-69

Part Name: Silicone Protective Cover   Part Number: As Shown

Test Procedure: 8-480087   Part Serial Number: As Shown

Test Pressure: N/A   Test Media: Flame 1400°F   Duration of Test: 10 sec.

Manufacturer	Serial Number	Remarks
1. Dow Corning (Silicone)	Silastic 55	Top — No visible damage from direct flame for 10 sec.
2.		
3.		Side — Limited damage fine checking of surface at 10 sec. of direct flame.
4.		
5.		Side — Same as above with what appeared to be a burning of surface impurities.
6.		
7.		
8.		Test results indicate Silastic 55 would provide a desirable flame protector for Burst Disc
9.		
10.		
11.		
12.		
13.		
14.		
15.		
16.		
17.		
18.		
19.		
20.		
21.		
22.		
23.		
24.		

Test Technician: J. Epperly 3/5   Test Engineer: J. Martin

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 10-7-69

Part Name Burst Disc Part Number Calmec RDS-106

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

A. Leakage

Leak Rate Before Pressure

Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure

Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test performed after Thermal Shock test.

Test Technician S. H. MOORE s/s

Test Engineer J. Mastrig

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 10-7-69

Part Name Burst Disc Part Number Fike A 3856-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks

This test performed after Thermal Shock test.

A. Leakage

Leak Rate Before Pressure Test $< 1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician S. H. Moore S/S

Test Engineer J. Martin

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 10-7-69

Part Name Burst Disc Part Number Fike A 3857-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks: This test performed after Thermal Shock test.

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician S.H. MOORE S/S

Test Engineer T. Martin

1.2.3.6.7 Shock Test

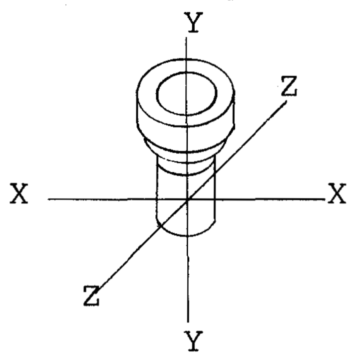
Requirements

The shock test is performed to evaluate the burst disc assembly's resistance to shock during normal service, installation, handling and shipment. The shock test was conducted in accordance with Section 10 of KSC-STD-164D. The test item is to be installed on the test fixture as shown in Figure 50 and tested in accordance with the following requirements:

A.	Pulse shape	one-half sine wave
B.	Duration	2 ms ± 0.6 ms or ± 15% whichever is greater
C.	Amplitude	30 g ± 15%
D.	Direction of axes as shown	

Procedure

The axes relative to the test specimen are defined below. Direction of shock was to be in both directions of each axis for each of the three (3) mutually perpendicular axes.



Sequence in which axes are to be tested:

(1)	Axis X	+ to - - to +
(2)	Axis Y	+ to - + t -
(3)	Axis Z	+ to - - to +

The test specimens were to be functionally leak tested in each axis prior to being rotated to another axis. Following the shock test in all three axes the test specimens were to be functionally leak tested.

Any visible defects noted as a result of this test were to be recorded. The test data from the shock test and functional test was to be recorded.

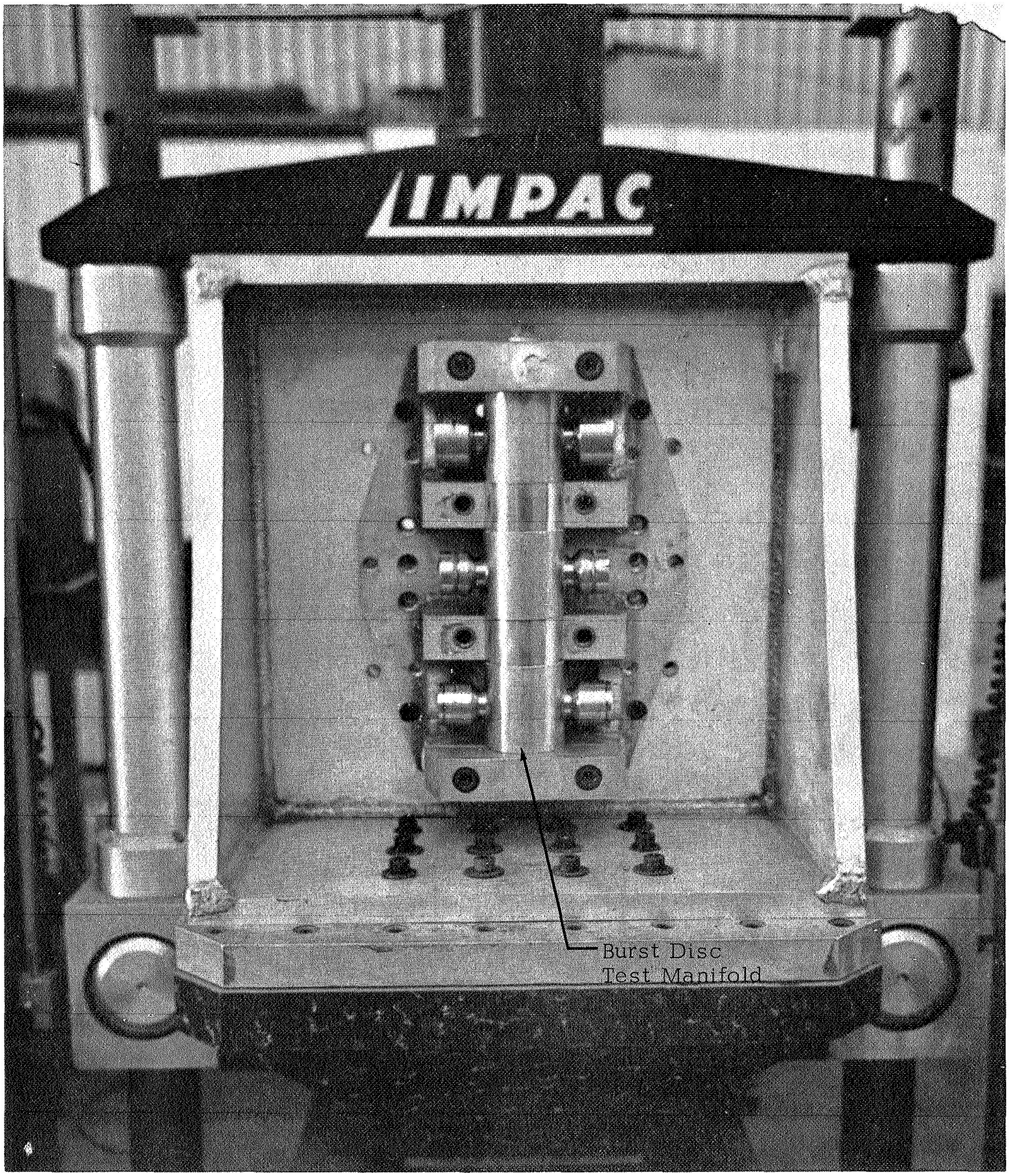
Test Results

The shock tests were completed for all burst disc assemblies. None of the specimens tested incurred structural damage as a result of the test. No leakage was detectable during the functional test on any specimen. See Figures 45, 46 and 47. They show the test units following testing in the X, Y and Z axis respectively.

The teflon coating on Fike A3857-1 S/N6 was found to be slightly cracked following the test as shown in Figure 48. Figure 49 depicts the sine wave curve for each axis of testing.

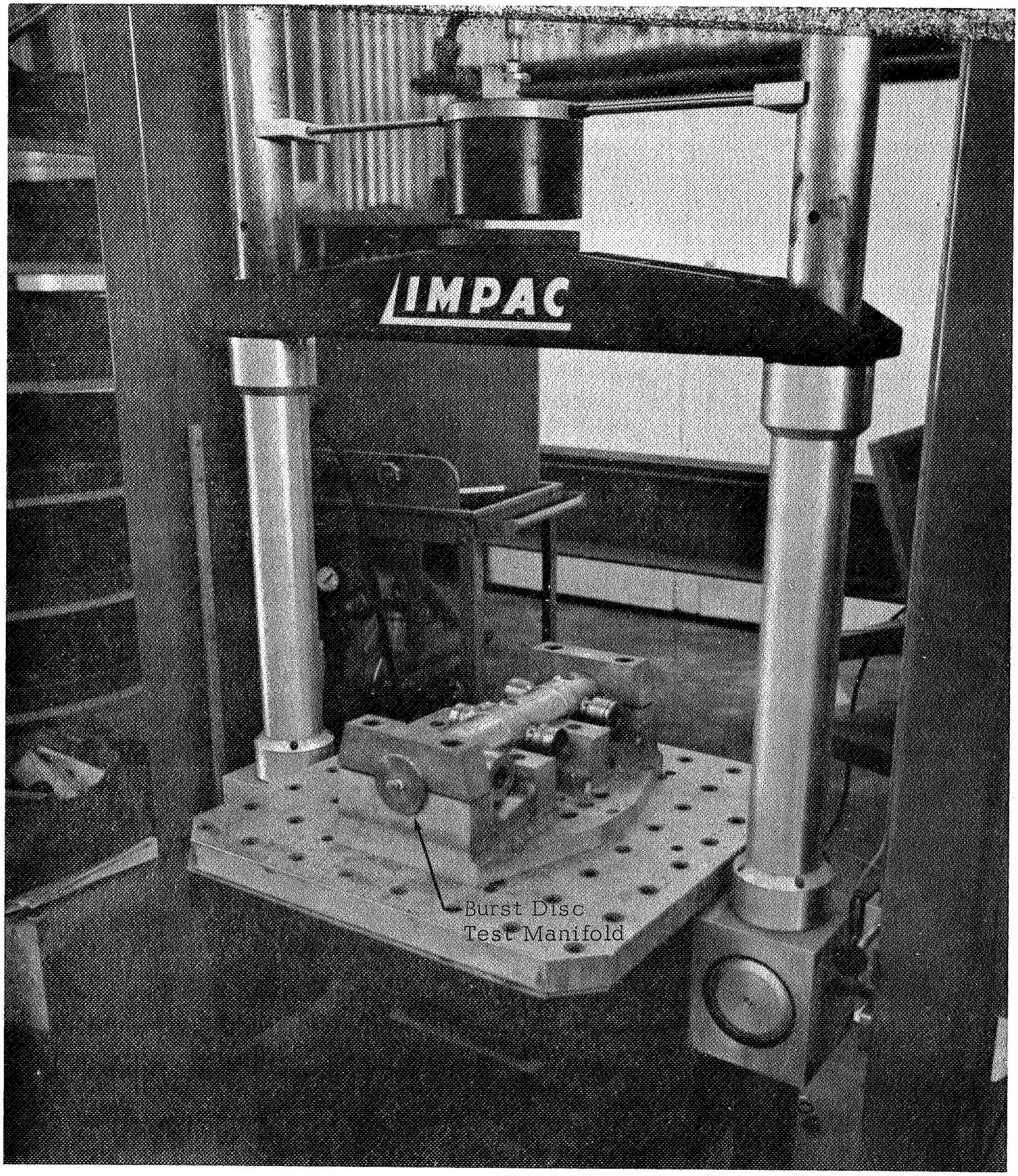
Test Data

The following test data sheets reflect the results of the shock test followed by the functional test.



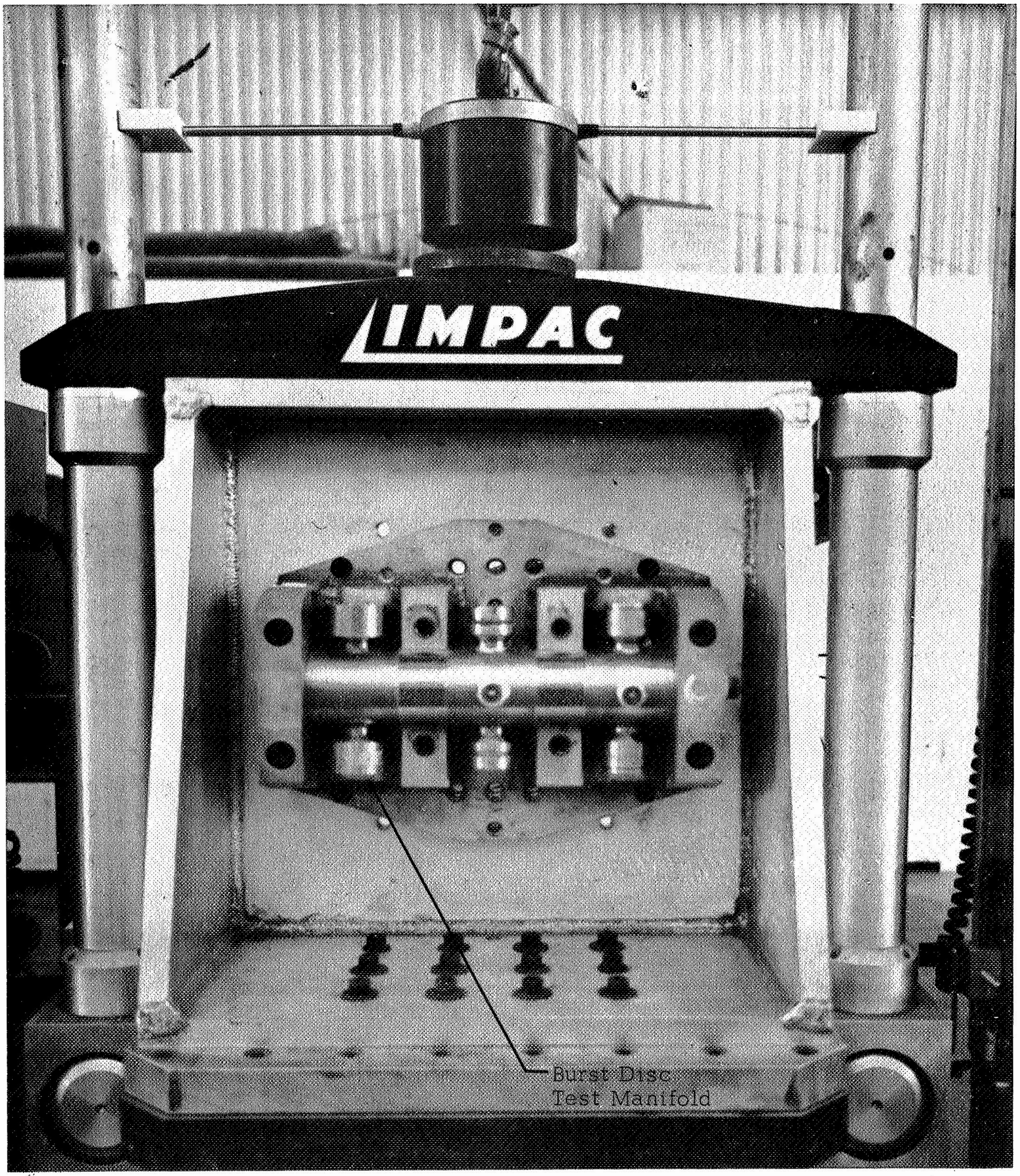
Shock Test Set-Up
Burst Discs
X Axis

Figure 45. Shock Test Set-Up - Burst Discs, X Axis



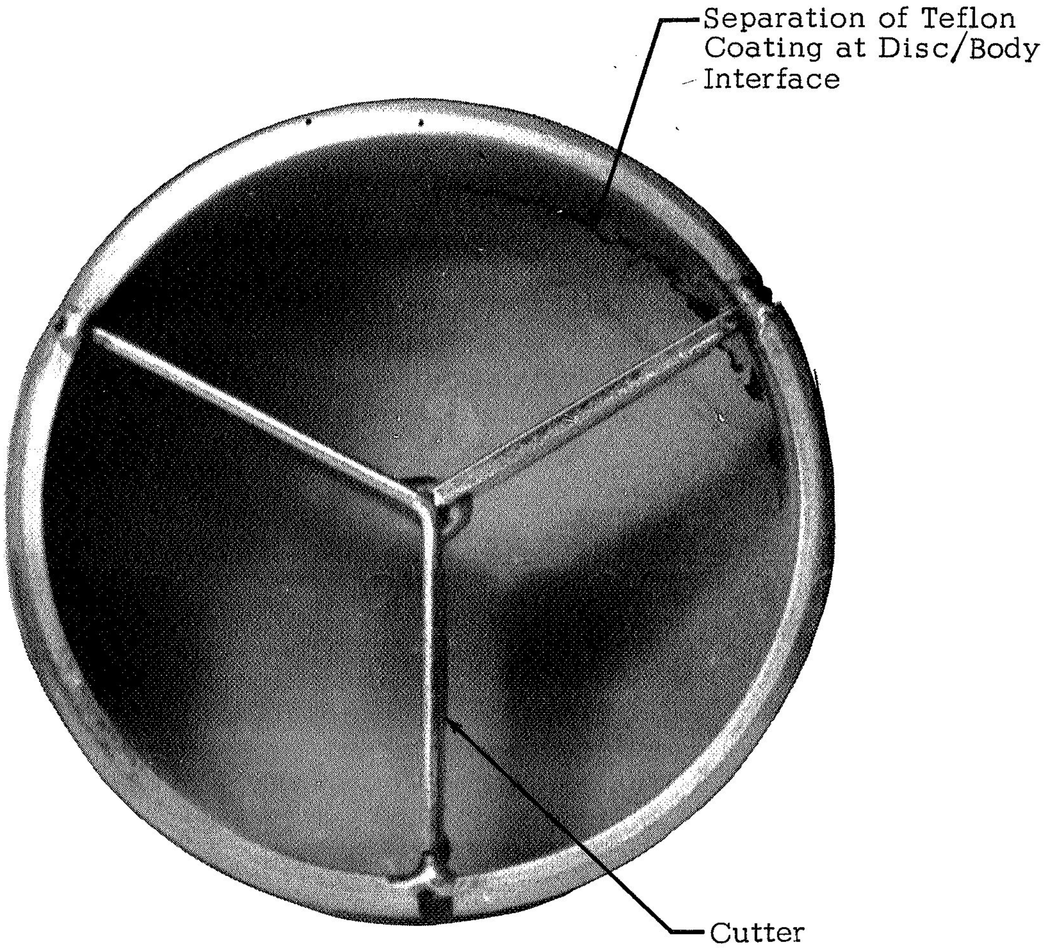
Shock Test Set-Up
Burst Discs
Z Axis

Figure 46. Shock Test Set-Up - Burst Discs, Z Axis



Shock Test Set-Up
Burst Disc

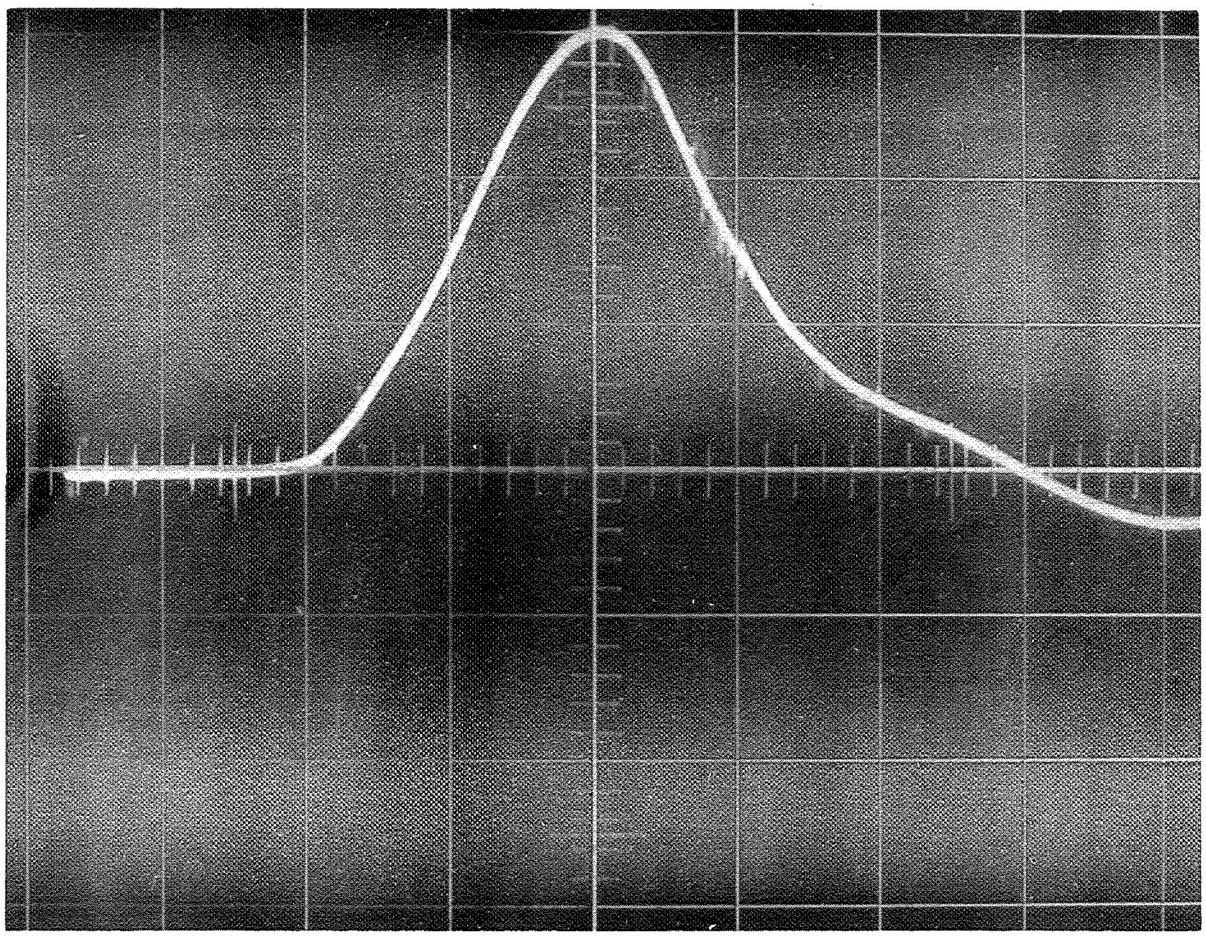
Figure 47. Shock Test Set-Up - Burst Discs, Y Axis



NOTE: Damage Noticed After Shock Test In 3 Axes.

Top View of Fike A3857-1 S/N6 All Welded Burst Disc

Figure 48. Damaged Disc - After Shock - 3 Axes



Typical Shock Pulse Waveform During Shock Test For Burst Discs, Seal-Off Valves, And Vacuum Probes

Figure 49. Shock Test - Force Curve

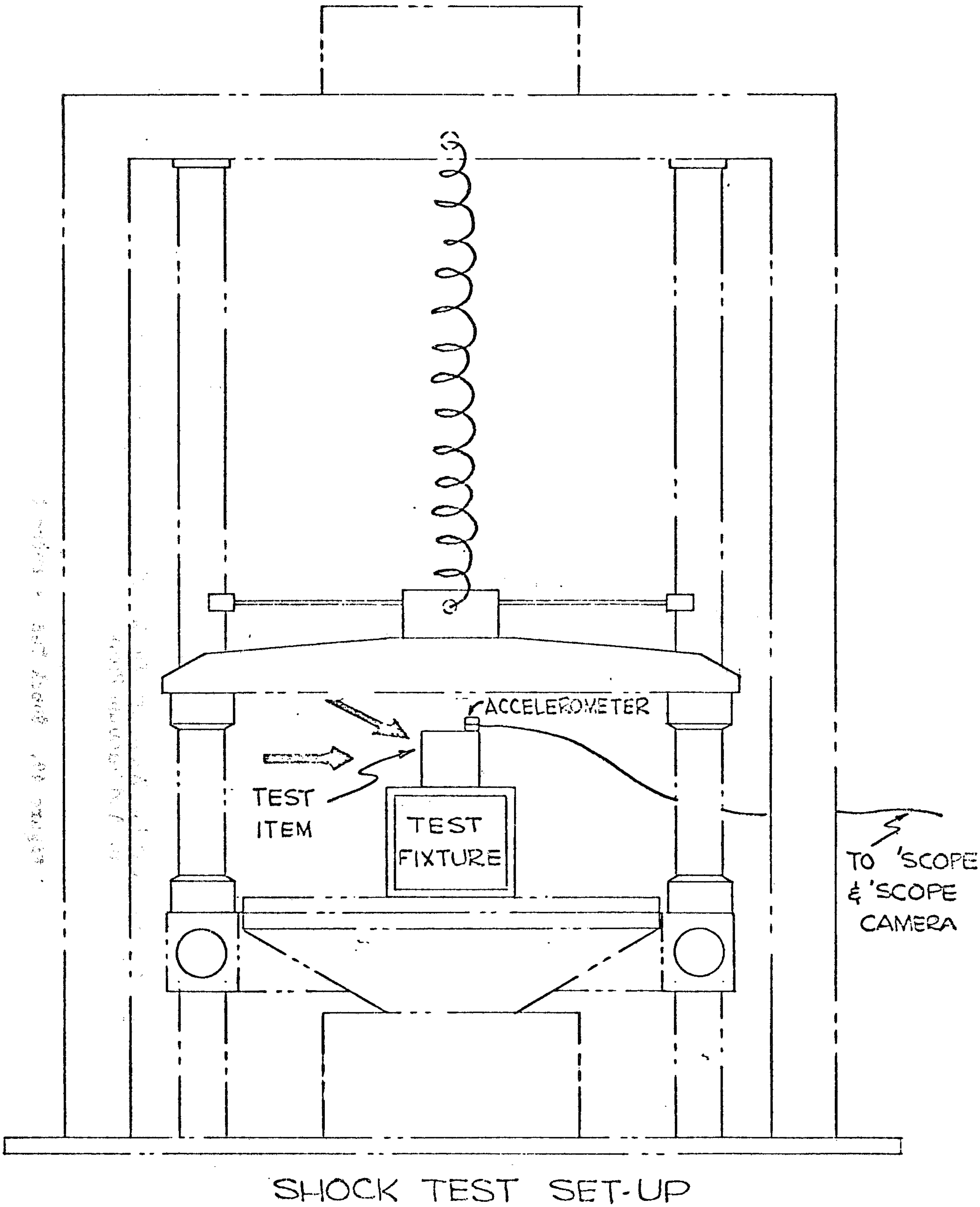


Figure 50. Shock Test Set-Up

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional

Date of Test 10-7-69

Part Name Burst Disc

Part Number Fike A 3857-1

Test Procedure 8-440087, Para 5.2

Part Serial Number 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test performed following X, Y, and Z axes shock.

Test Technician J. Epperly s/s

Test Engineer J. Martins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 10-8-69

Part Name Burst Disc Part Number Calmec RDS-106

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test performed following X, Y, and Z axes shock.

Test Technician S. H. MOORE 5/5

Test Engineer J. Martins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 10-8-69

Part Name Burst Disc Part Number Fike A 3856-1

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks

This test performed following X, Y, and Z axes shock.

A. Leakage

Leak Rate Before Pressure Test $<1 \times 10^{-10}$ scc/sec

Leak Rate After Pressure Test $<1 \times 10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician S. H. MOORE S/S

Test Engineer J. Martins

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Shock Date of Test: 10-7-69

Part Name: Burst Disc Part Number: Fike A 3857-1

Test Procedure: 8-480087 Part Serial Number: 1 - 10

Drop No.	Axis	Remarks
1	X + to -	No visible damage
2	X - to +	No visible damage
3	Y + to -	No visible damage
4	Y - to +	No visible damage
5	Z + to -	No visible damage
6	Z - to +	No visible damage

S/N 6 teflon coating on the disc diaphragm was found to be cracked following the three axes of shock.

Test Technician: S. MOORE S/S

Test Engineer: J. MARTINEZ S/S

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Shock　　Date of Test 10-7-69

Part Name Burst Disc　　Part Number Fike A 3856-1

Test Procedure 8-480087　　Part Serial Number 1 - 10

Drop No.	Axis	Remarks
1	X + to -	No visible damage
2	X - to +	No visible damage
3	Y + to -	No visible damage
4	Y - to +	No visible damage
5	Z + to -	No visible damage
6	Z - to +	No visible damage

Test Technician S. MOORE S/S

Test Engineer J. MARTINEZ S/S

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Shock Date of Test 10-7-69

Part Name Burst Disc Part Number Calmec RDS-106

Test Procedure 8-480087 Part Serial Number 1 - 10

Drop No.	Axis	Remarks
1	X + to -	No visible damage
2	X - to +	No visible damage
3	Y + to -	No visible damage
4	Y - to +	No visible damage
5	Z + to -	No visible damage
6	Z - to +	No visible damage

Test Technician S. MOORE s/s

Test Engineer J. MARTINEZ s/s

1.2.3.6.8 Vibration Test

Requirements

The vibration test was to be performed to determine the test item's integrity in the predicted vibration environment.

The test item was to be installed in a test fixture as shown in Figure 54. The test item was to be subjected to vibration tests in accordance with KSC-STD-164D, Paragraph 9.2, and Procedure I, Paragraphs 9.3.1 and 9.3.2, except that the test levels were to be specified in this document.

The entire sequence of vibration test was to be accomplished three times (once in each of the principal axes) and all testing was to be completed in one axis before changing axes. The test sequence in each axis was to be (1) resonant frequency search and sinusoidal sweep. (See Figures 51 and 52)

Throughout the vibration test program, the test item was to be functionally monitored for possible failure (see Figure 53). Prior to testing in each axis, the test item was to be functionally tested.

Requirement Resonant Search

The test item was to be installed in accordance with Para. 4.4.1 of KSC-STD-164D. The fixture/test item assembly was to be exposed to sinusoidal vibration at an acceleration level of 3 g. The frequency range of 20 to 3000 cps was to be traversed logarithmically in directions of both increasing and decreasing for a total period of 15 minutes per axis maximum. The test item was to be functionally tested at the conclusion of the test.

Sinusoidal Sweep

The fixture/test item assembly was to be exposed to sinusoidal sweep vibration under conditions found in Figure 55, Curve B, at an acceleration of 30 g. The frequency range of 10 to 2000 cps was to be traversed logarithmically in directions of both increasing and decreasing frequency for a total test period of 20 minutes (10 minutes increasing and 10 minutes decreasing). The test item was to be functionally leak tested at the conclusion of the test.

Test Results

Vibration tests were completed for all burst discs in each of the three axes tested. The specimens were stable throughout the frequency range from 20 to 1800 cps. At 1800 cps, the low torque retainer caps on the AMETEK/Calmec RDS-106 unscrewed. This occurred on two of the ten specimens tested. Retightening the cap eliminated the problem and leakage. On one of the Calmec (S/N 8) specimens, the nut, disc plug and cutter came completely off the body without any subsequent leakage. Apparently the vacuum kept the diaphragm from coming off also. The cutter and diaphragm separation was due to tack welds that had been broken prior to vibration. This had occurred as a result of the many assembly-disassembly operations performed on these discs.

Functional leakage tests were performed following vibration with no detectable leakage.

The Z axis sinusoidal sweep was conducted at 15 gs for each component. This was due to problems experienced with the power amplifier and inability to generate the required 30 g force. This does not create problems since the X and Z axes are identical and the X and Y axes were vibrated at 30 gs.

Random vibration was not conducted.

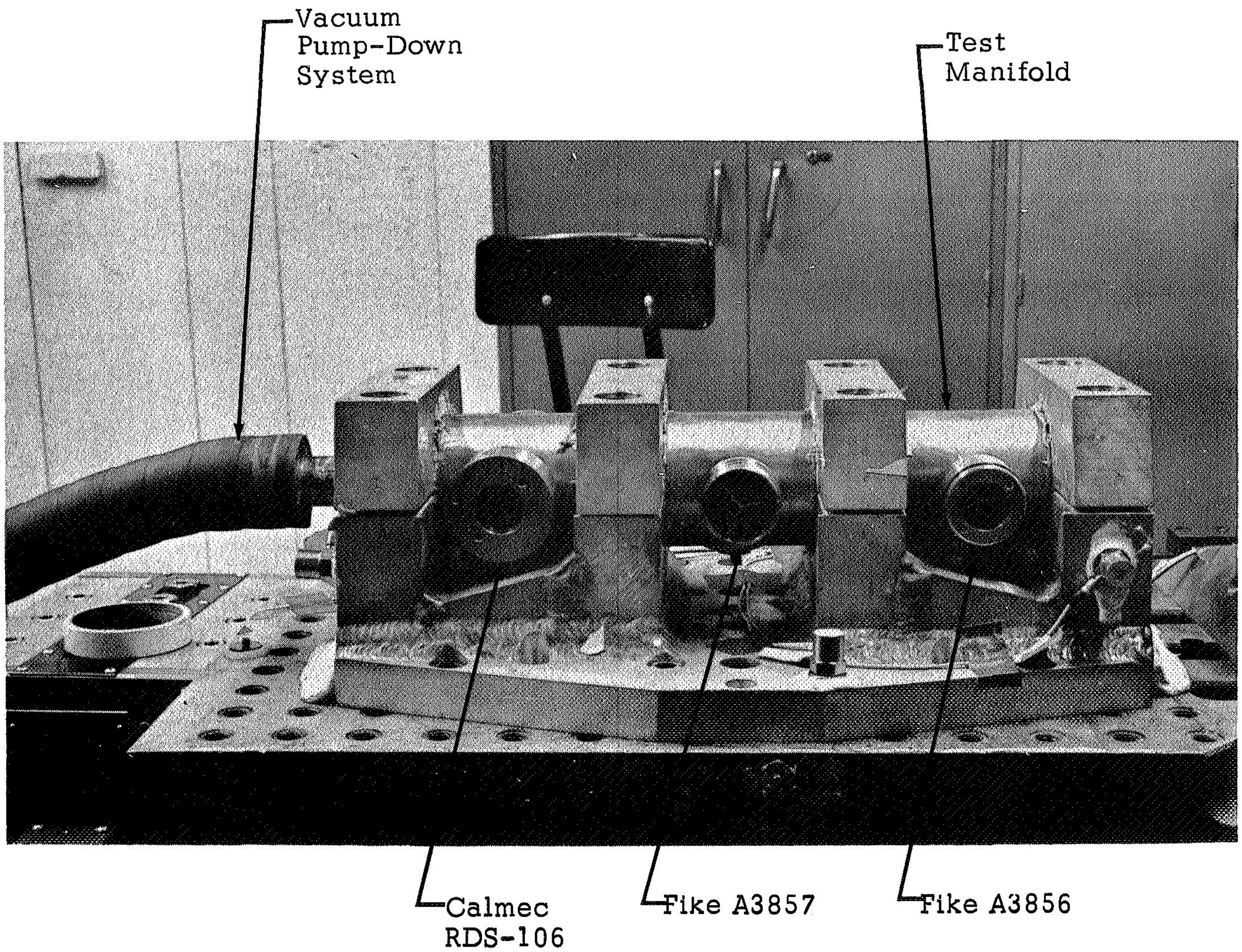
Paragraph 5.12.2.3 of Test Procedure 8-480091 Random Excitation was not performed for the following reasons:

A. The sine vibration for this particular hardware that was performed subjected the specimen to a more severe test than would be experienced in random vibration.

B. Fixture equalization required to perform random vibration for each component would cost in excess of benefits gained.

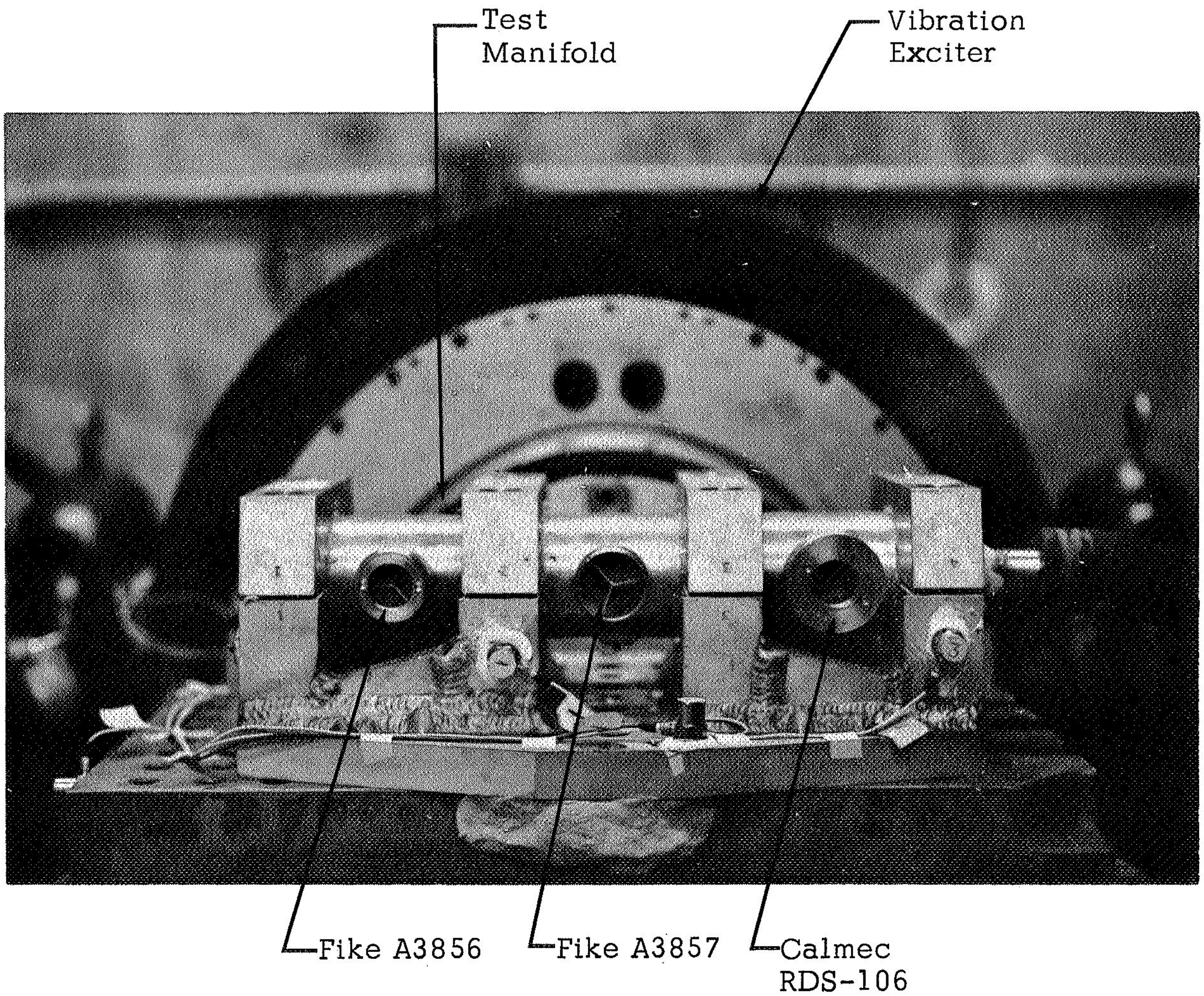
Test Data

The following test data sheets and photographs reflect the results of the vibration test followed by the functional leak test.



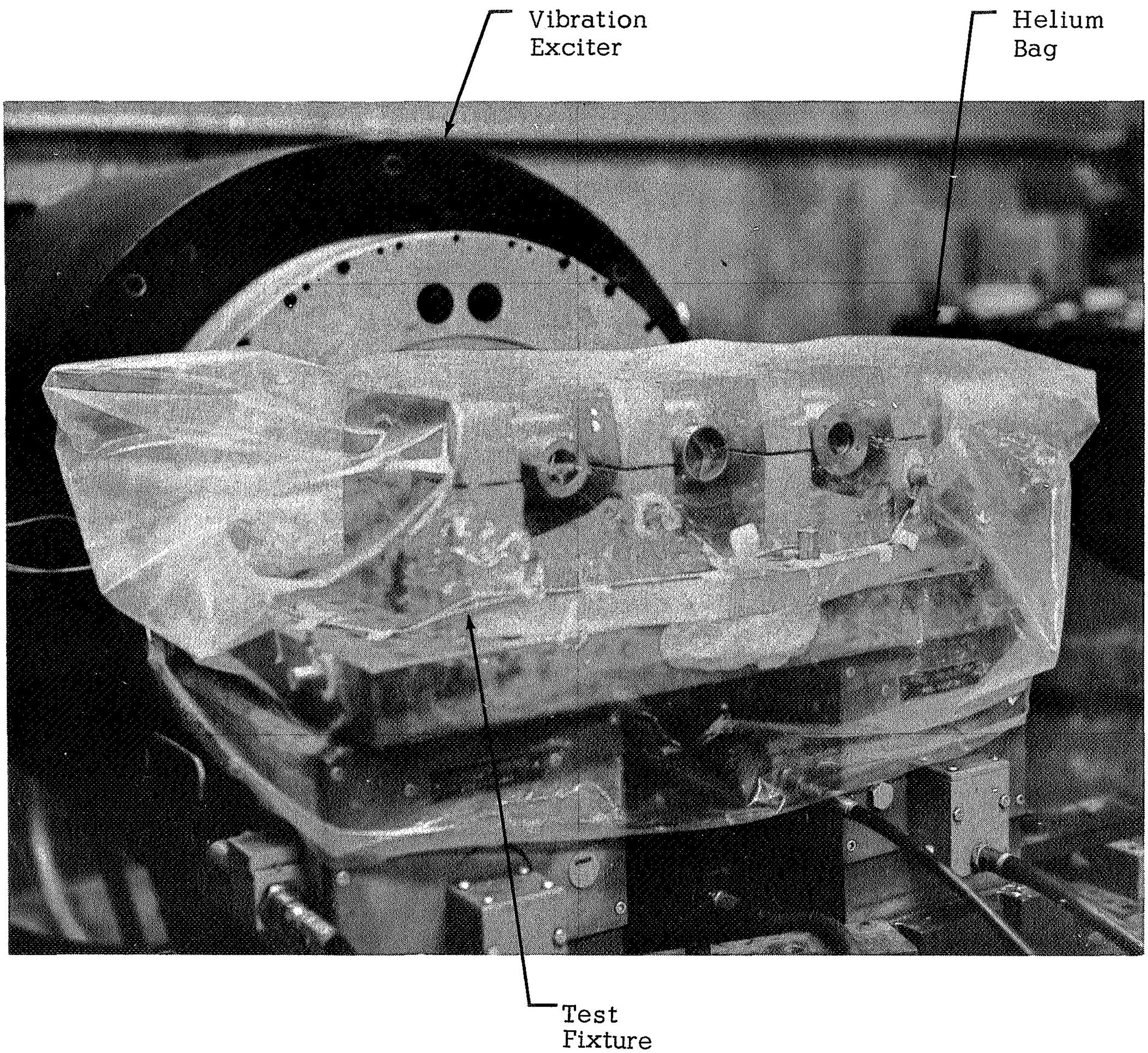
Burst Disc Vibration Test — Z Axis

Figure 51. Vibration Z Axis - Burst Disc



Burst Disc Vibration Test — Y Axis

Figure 52. Vibration Y Axis - Burst Disc



Burst Disc Vibration Test — Y Axis

Figure 53. Vibration Test Showing Leak Monitoring Method

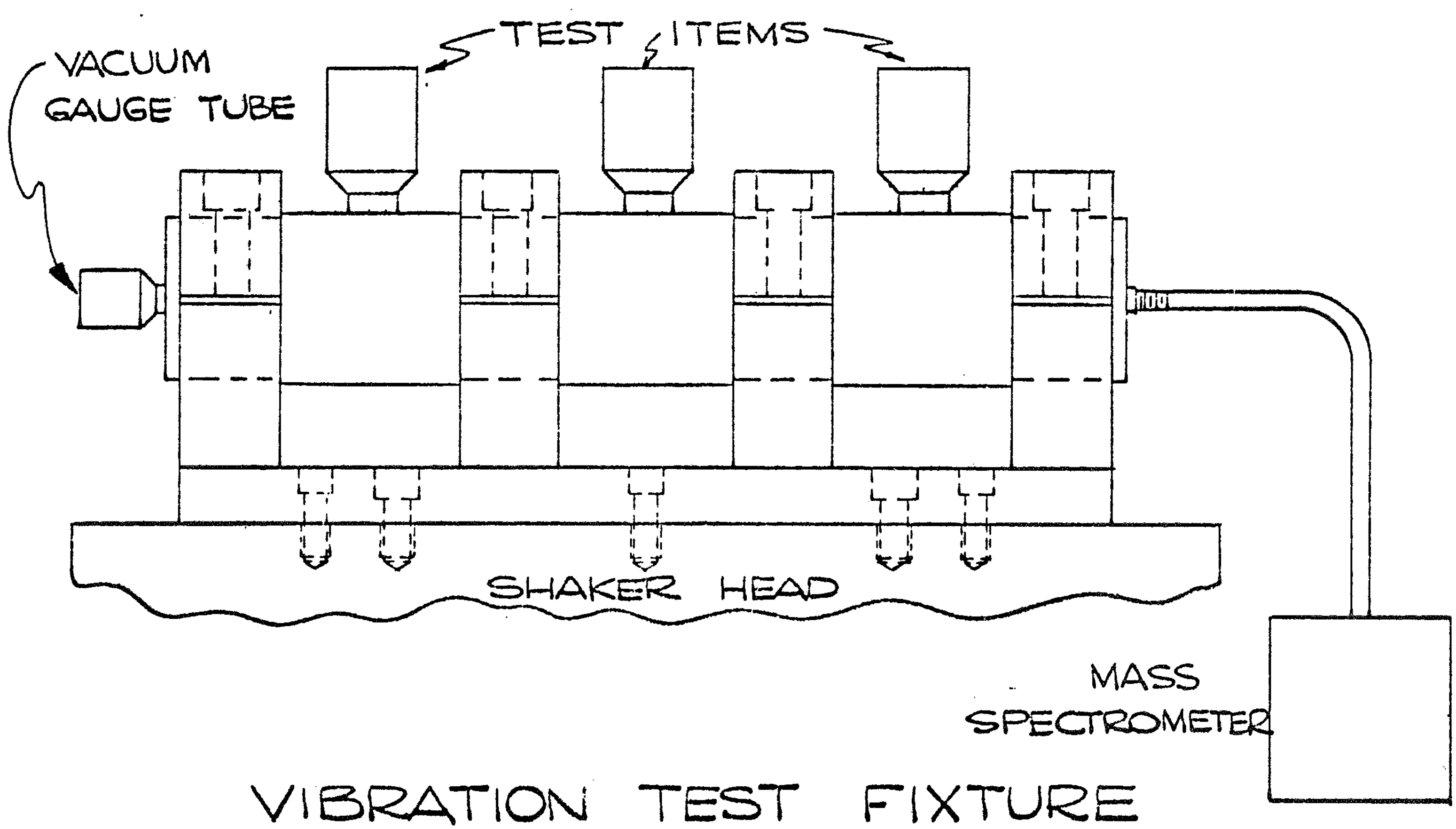


Figure 54. Vibration Test Fixture

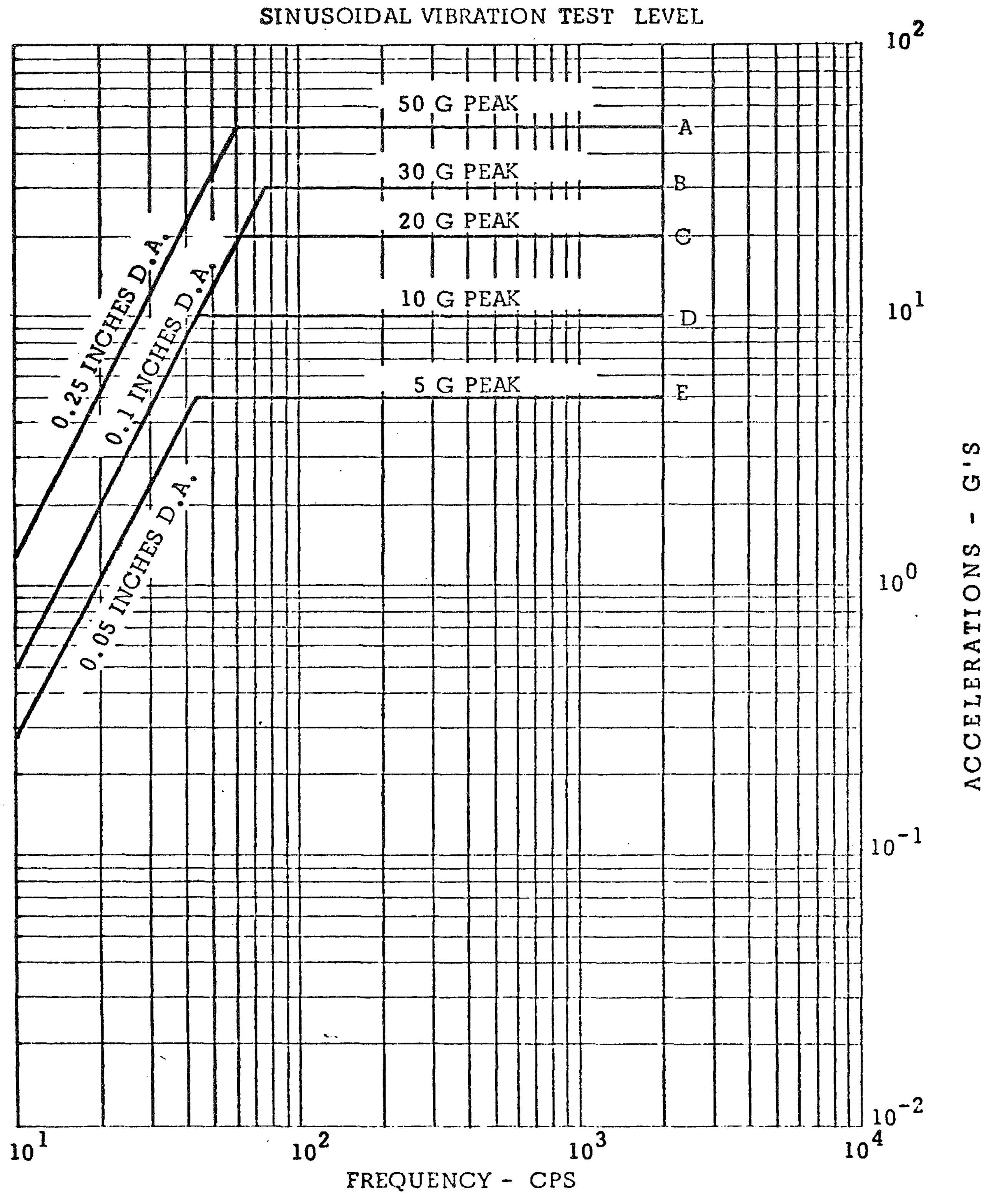


Figure 55. Sinusoidal Vibration Test Level

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration | Date of Test 11-4-69

Part Name Burst Disc | Part Number Fike A 3857-1

Test Procedure 8-480090 | Part Serial Number 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Type of Recorder Sanborn 350 | No. of Channels 6

Recording Calibration 0-10 g's RMS, 0-100 g's RMS

Bolt Torque Values

Accelerometer Placement Sketch

See Photo

Sine cond	Search Time 25°/Min.	
	Sweep Time 16°/Min.	
Search	20 to 75cps @ 0.01 in. D.A.	
	75 to 3000cps @ 3 G's peak	
Sweep	10 to 75cps @ 0.10 in. D. A.	
	75 to 2000cps @30 G's peak	
Z Axis Sweep	10 to 75cps @ 0.05 in. D. A.	
	75 to 1500cps @15 G's peak	
Random Cond.	Random Noise Duration	
	to cps @ in. 2/cps	
	to cps @ G 2/cps	
	to cps @ db octave	
	to cps @ G 2/cps	
	to cps @ db octave	

Resonant Search

Sweep Time

Resonant Frequency	AXIS X	Y	Z
None			
"			
"			

Axis	Remarks	Search ~~XXXXX~~ time and Sweep time	Operator
X	No Failure	15 Min. 20 Min.	10/1/69 D.V.T.
Y	No Failure	15 Min. 20 Min.	10/29/69 D.V.T.
Z	No Failure	15 Min. 20 Min.	10/24/69 D.V.T.

Test Technician D.C. Van Tieghem s/s Inspection

Test Engineer J. Mathis

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Vibration | Date of Test: 11-4-69

Part Name: Burst Disc | Part Number: Calmec RDS-106

Test Procedure: 8-480090 | Part Serial Number: 1, 2, 3, 5, 7, 9, & 10

Type of Recorder: Sanborn 350 | No. of Channels: 6

Recording Calibration: 0-10 g's RMS / 0-100 g's RMS

Bolt Torque Values: ______

Sine cond	Search Time 25°/Min. Sweep Time 16°/Min.	
Search	20 to 75 cps @ 0.01 in. D.A.	
	75 to 3000 cps @ 3 G's peak	
Sweep	10 to 75 cps @ 0.10 in. D. A.	
	75 to 2000 cps @ 30 G's peak	
Z Axis Sweep	10 to 75 cps @ 0.05 in. D. A.	
	75 to 1500 cps @ 15 G's peak	

Accelerometer Placement Sketch

See Photo

Random Cond.	Random Noise Duration ______
	___ to ___ cps @ ___ in. 2/cps
	___ to ___ cps @ ___ G 2/cps
	___ to ___ cps @ ___ db octave
	___ to ___ cps @ ___ G 2/cps
	___ to ___ cps @ ___ db octave

Resonant Search

Sweep Time

Resonant Frequency	AXIS X	Y	Z
None			
"			
"			

Axis	Remarks	~~XXXXX~~ Search time and Sweep time	Operator
X	No Failure	15 Min. 20 Min.	10/10/69 D.V.T.
Y	No Failure	15 Min. 20 Min.	10/30/69 D.V.T.
Z	No Failure	15 Min. 20 Min.	10/24/69 D.V.T.

Test Technician: D.C. VAN TIEGHAM s/s Inspection: ______

Test Engineer: J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration　Date of Test 11-4-69

Part Name Burst Disc　Part Number Calmec RDS-106

Test Procedure 8-480090　Part Serial Number 8

Type of Recorder Sanborn 350　No. of Channels 6

Recording Calibration 0-10 g's RMS, 0-100 g's RMS

Bolt Torque Values

Accelerometer Placement Sketch

See Photo

Sine cond	Search Time	25°/Min.
	Sweep Time	16°/Min.
Search	20 to 75 cps @ 0.01 in. D.A.	
	75 to 3000 cps @ 3 G's peak	
Sweep	10 to 75 cps @ 0.10 in. D. A.	
	75 to 2000 cps @ 30 G's peak	
Z Axis Sweep	10 to 75 cps @ 0.05 in. D. A.	
	75 to 1500 cps @ 15 G's peak	
Random Cond.	Random Noise Duration	
	to cps @ in. 2/cps	
	to cps @ G 2/cps	
	to cps @ db octave	
	to cps @ G 2/cps	
	to cps @ db octave	

Resonant Search

Sweep Time

Resonant Frequency	AXIS X	AXIS Y	AXIS Z
None			
"			
"			

Axis	Remarks	~~XXXXX~~ Search time and Sweep time	Operator
X	Retaining Ring Became Loose During Sweep — No Leakage	15 Min. 20 Min.	10/1/69 D.V.T.
Y	Retaining Ring Became Loose During Sweep — No Leakage	15 Min. 20 Min.	10/29/69 D.V.T.
Z	No Failure	15 Min. 20 Min.	10/24/69 D.V.T.

Test Technician D.C. VAN TIEGHAN 5/5　Inspection

Test Engineer J. Masting

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Vibration — Date of Test: 11-4-69

Part Name: Burst Disc — Part Number: Calmec RDS-106

Test Procedure: 8-480090 — Part Serial Number: 4 & 6

Type of Recorder: Sanborn 350 — No. of Channels: 6

Recording Calibration: 0 - 10 g's RMS; 0 - 100 g's RMS

Bolt Torque Values: ______

Sine cond	Search Time 25°/Min. Sweep Time 16°/Min.	**Accelerometer Placement Sketch**
Search	20 to 75cps @ 0.01 in. D.A.	See Photo
	75 to 3000cps @ 3 G's peak	
Sweep	10 to 75cps @ 0.10 in. D. A.	
	75 to 2000cps @ 30 G's peak	
Z Axis Sweep	10 to 75cps @ 0.05 in. D. A.	
	75 to 1500cps @ 15 G's peak	

Random Cond.	Random Noise Duration ______
	___ to ___ cps @ ___ in. 2/cps
	___ to ___ cps @ ___ G 2/cps
	___ to ___ cps @ ___ db octave
	___ to ___ cps @ ___ G 2/cps
	___ to ___ cps @ ___ db octave

Resonant Search

Sweep Time

Resonant Frequency	AXIS X	AXIS Y	AXIS Z
None			
"			
"			

Axis	Remarks	Search ~~Dwell~~ time and Sweep time	Operator
X	Retaining Ring Became Loose During Sweep — No Leakage	15 Min. 20 Min.	10/10/69 D.V.T
Y	No Failure	15 Min. 20 Min.	10/29/69 D.V.T
Z	No Failure	15 Min. 20 Min.	10/29/69 D.V.T.

Test Technician: D.C VAN TIEGHAM S/S — Inspection: ______

Test Engineer: J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration   Date of Test 11-4-69

Part Name Burst Disc   Part Number Fike A 3856-1

Test Procedure 8-480090   Part Serial Number 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Type of Recorder Sanborn 350   No. of Channels 6

Recording Calibration 0-10 g's RMS / 0-100 g's RMS

Bolt Torque Values ______

Sine cond	Search Time 25°/Min. Sweep Time 16°/Min.	
Search	20 to 75 cps @ 0.01 in. D.A.	
	75 to 3000 cps @ 3 G's peak	
Sweep	10 to 75 cps @ 0.10 in. D. A.	
	75 to 2000 cps @ 30 G's peak	
Z Axis Sweep	10 to 75 cps @ 0.05 in. D. A. 75 to 1500 cps @ 15 G's peak	
Random Cond.	Random Noise Duration ______	
	___ to ___ cps @ ___ in. 2/cps	
	___ to ___ cps @ ___ G 2/cps	
	___ to ___ cps @ ___ db octave	
	___ to ___ cps @ ___ G 2/cps	
	___ to ___ cps @ ___ db octave	

Accelerometer Placement Sketch

See Photo

Resonant Search

Sweep Time

Resonant Frequency	AXIS X	Y	Z
None			
"			
"			

Axis	Remarks	Sweep ~~XXXXX~~ time and Sweep time	Operator
X	No Failure	15 Min. 20 Min.	10/10/69 D.V-T.
Y	No Failure	15 Min. 20 Min.	10/29/69 D.V.T.
Z	No Failure	15 Min. 20 Min.	10/24/69 D.V.T.

Test Technician D.C. VAN TIEGHAM 5/5   Inspection ______

Test Engineer J. Martine

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 11-3-69

Part Name Burst Disc Part Number Fike A 3857

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

Remarks

This test performed following vibration in X, Y, and Z Axes

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Test Technician S. H. Moore s/s

Test Engineer J. Martin

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Functional Date of Test 11-3-69

Part Name Burst Disc Part Number Calmec RDS-106

Test Procedure 8-440087, Para 5.2 Part Serial Number 1 - 10

A. Leakage

Leak Rate Before Pressure

Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure

Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure 20 ±2 psig

Test Media GN_2

Duration of Test 2 min.

Remarks

This test performed following vibration in X, Y, and Z axes.

Test Technician S. H. MOORE S/S

Test Engineer J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Functional Date of Test: 11-3-69

Part Name: Burst Disc Part Number: Fike A 3856

Test Procedure: 8-440087, Para 5.2 Part Serial Number: 1 - 10

A. Leakage

Leak Rate Before Pressure Test $< 1x10^{-10}$ scc/sec

Leak Rate After Pressure Test $< 1x10^{-10}$ scc/sec

B. Pressure Test

Test Pressure: 20 ±2 psig

Test Media: GN_2

Duration of Test: 2 min.

Remarks

This test performed following vibration in X, Y, and Z axes.

Test Technician: S. H. Moore 5/5

Test Engineer: J. Martine

1.2.3.6.9 Burst Pressure Test

Requirements

The burst pressure test is performed to determine if the test can withstand the specified burst pressure without rupture and to determine at what pressure the test item will rupture.

Several discs with dented surface were also to be tested to determine effects of dents on burst tolerance. (These discs were dented to simulate handling damage). This part of the test is not a controlled test and results are for comparison only.

Procedure

Specific test parameters and levels are as follows:

A.	Burst Pressure	30 ± 5 psig
B.	Test Media	Nitrogen Gas
C.	Test Duration	Two (2) minutes at burst pressure

The test item was to be installed in a test set-up as shown in Figure 61 and pressurized at an increase rate of not more than 5 psig/minute to burst pressure and maintained for two minutes. If rupture did not occur, pressure was to be increased in one (1) psig increments, increase not to exceed one (1) psig/minute until rupture occurred. The rupture pressure, test media and test duration at burst pressure was to be recorded.

Test Results

Each type of burst disc configuration was subjected to the burst pressure test. Number of specimens burst tested are:

	Undamaged	Damaged
AMETEK/Calmec	12	1
Fike A3856-1	10	3
Fike A3857-1	6	-

Ten (10) AMETEK/Calmec RDS-106 replaceable disc assemblies, ten (10) Fike A3856 replaceable disc assemblies, and six (6) Fike A3857 all welded disc assemblies were burst tested. The following shows the burst pressure for each type tested:

	Actual Burst Pressure
AMETEK/Calmec, RDS-106 Replaceable Assembly	37 psig - 1 disc
S/N 1 through 12	39 psig - 5 discs
Rated burst pressure - 37 psig	40 psig - 1 disc
	41 psig - 4 discs
	43 psig - 1 disc

Fike A 3856 (Replaceable Assembly S/N 1 through 10 Rated burst pressure - 29 psig	24 psig - 1 disc 26 psig - 2 discs 28 psig - 1 disc 29 psig - 2 discs 30 psig - 1 disc 32 psig - 1 disc 34 psig - 1 disc 37 psig - 1 disc
Fike A 3857 (All welded) S/N 1, 2, 4, 6, 7 & 9 Rated burst pressure - 33 psig	30 psig - 1 disc 34 psig - 1 disc 35 psig - 3 discs 39 psig - 1 disc

Figures 58, 59 and 60 show the burst disc assemblies following burst pressure testing. Four specimens were dented prior to testing. All of these discs showed an uneven distribution of load across the face following burst test. In several discs, as much as 40% of the disc surface did not buckle. (Discs that are not dented buckle across the entire surface).

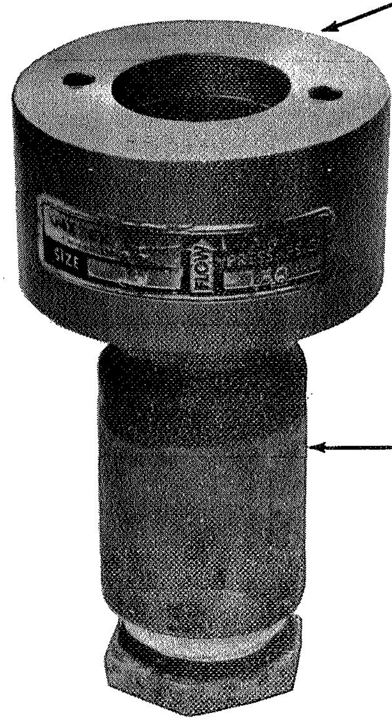
Each of the four (4) damaged discs reversed against the cutter blade at 10 psig. Rupture occurred at 20 psig on the three (3) Fike A3856 and at 23 psig on the one (1) AMETEK/Calmec RDS-106. Figures 56 and 57 depict the semi-buckled condition of pre-dented discs.

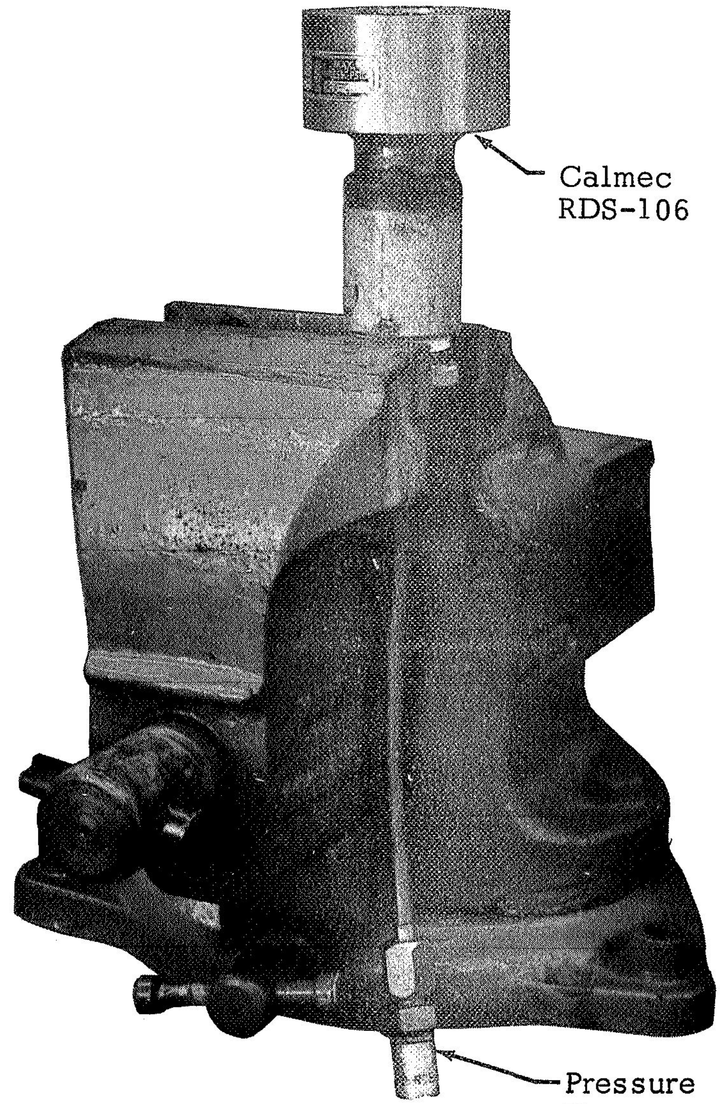
Examination of the burst discs (Figures 56 through 59) show that a full flow opening of the diaphragm was not attained at burst. These results were expected since the low gas volume pressure tests were conducted.

The testing method determines the actual burst pressure to a closer tolerance than can be readily attained using a large volume of stored gas.

Data Sheets

The following test data sheets and photographs reflect the results of the burst pressure test.





Burst Disc Burst Test Setup

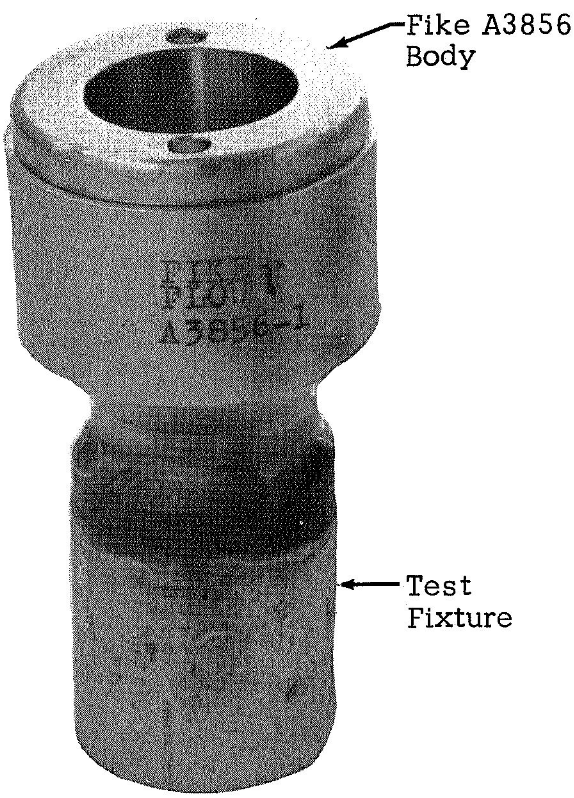
NOTE: Diaphragm on left side did not buckle across total surface.

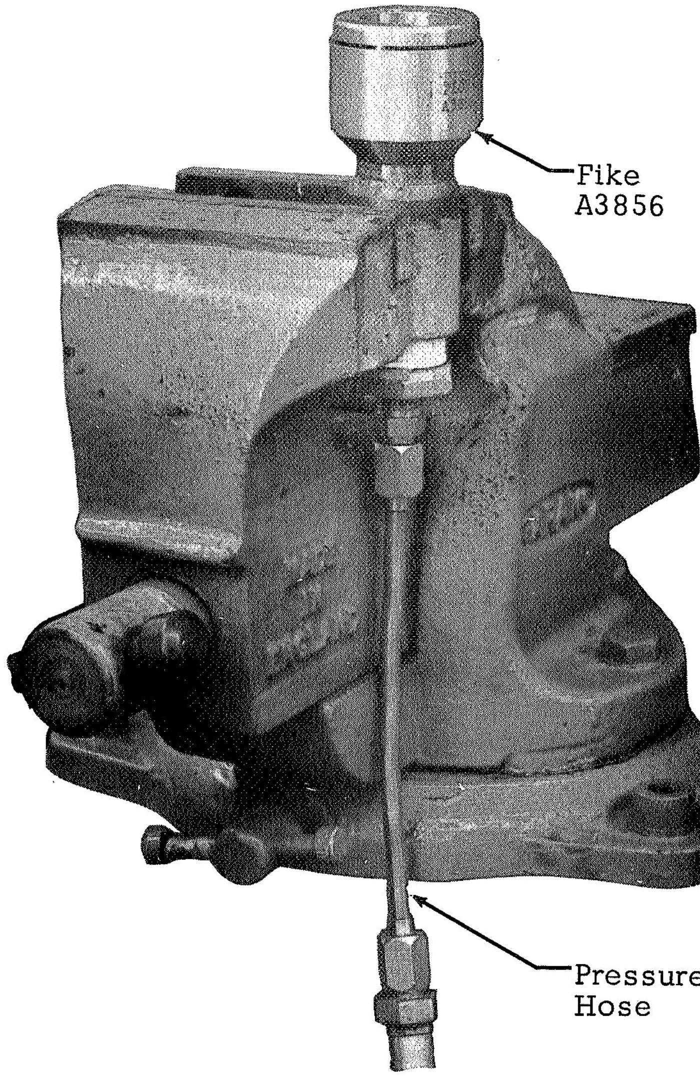
Burst At 23 psig (Damaged Prior To Burst) | Burst At 39 psig | Burst At 37 psig

Burst Disc Burst Test Specimens

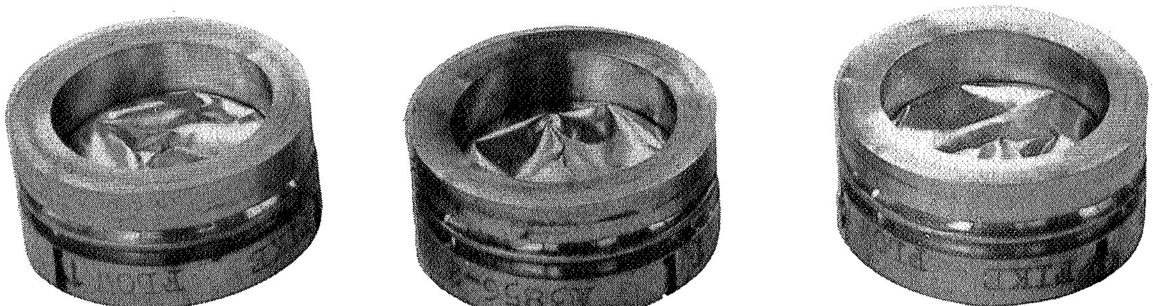
Figure 56. Burst Test - Calmec Burst Discs

Burst Disc Burst Test Specimens





Burst Disc Burst Pressure Setup

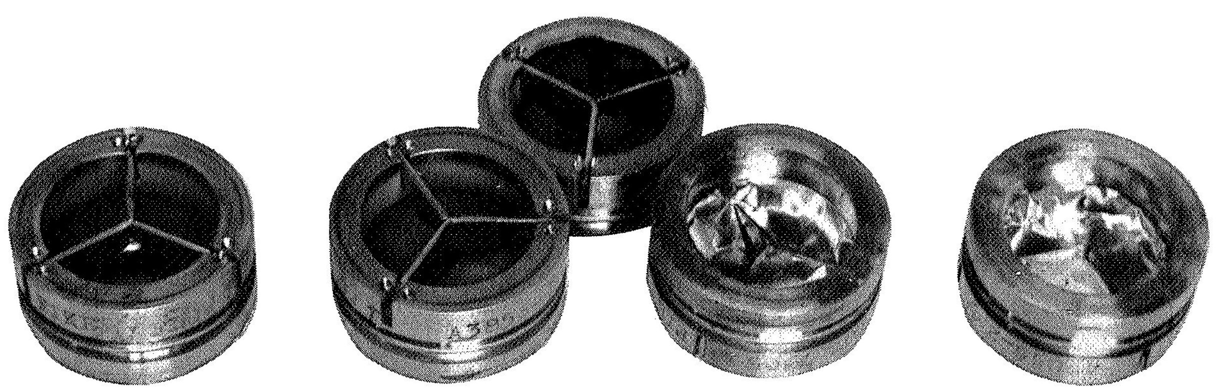


Each Specimen Buckled At 10 psi — Ruptured at 20-21 psig

NOTE: That buckling did not occur across total surface due to damaged surface

Figure 57. Burst Test - Fike Burst Discs

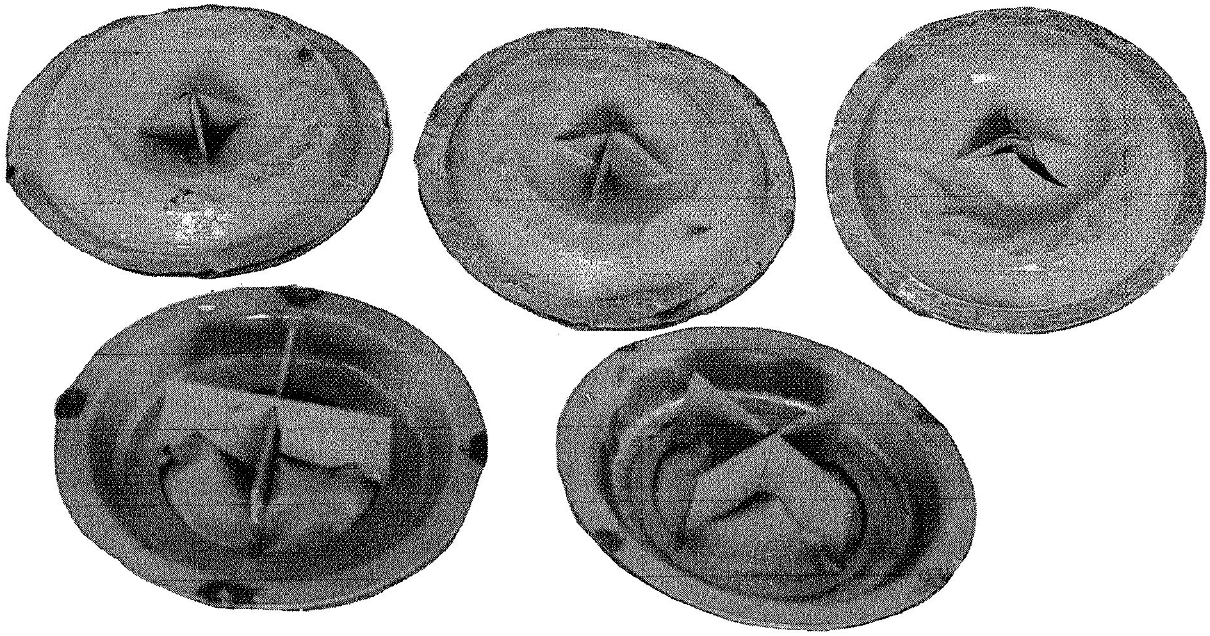
Note Complete Penetration Of Cutter Into Disc Diaphragm



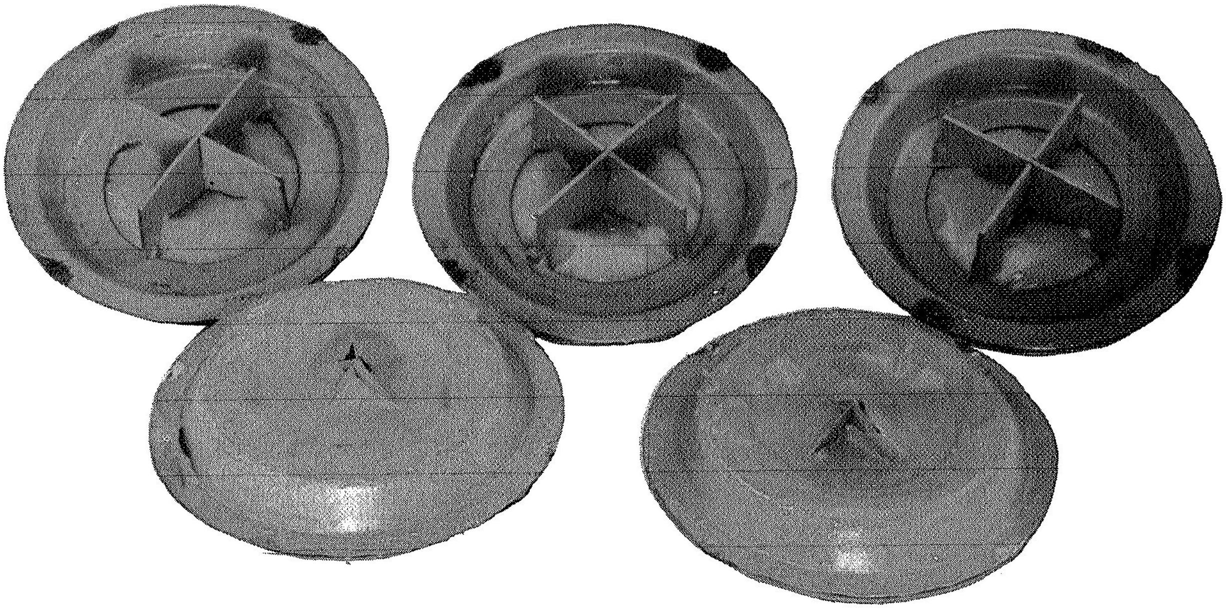
Rated Burst Pressure — 29 psig
All Specimens Burst Within ±8 psig

Fike A 3856-1 Burst Disc — Replaceable Assemblies
Burst Test Results

Figure 58. Burst Test - Fike Replaceable Burst Discs



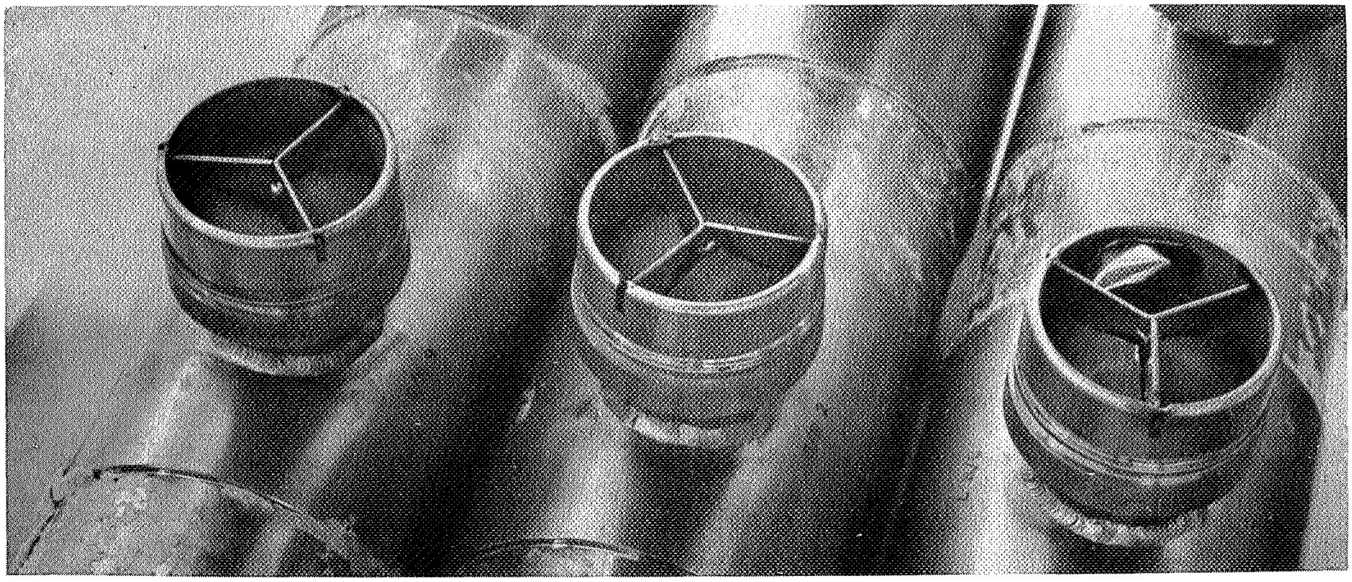
Note That Perforation Was Not Complete In Several Diaphragms



Rated Burst Pressure - 37 psig
All Specimens Burst Within ± 6 psig

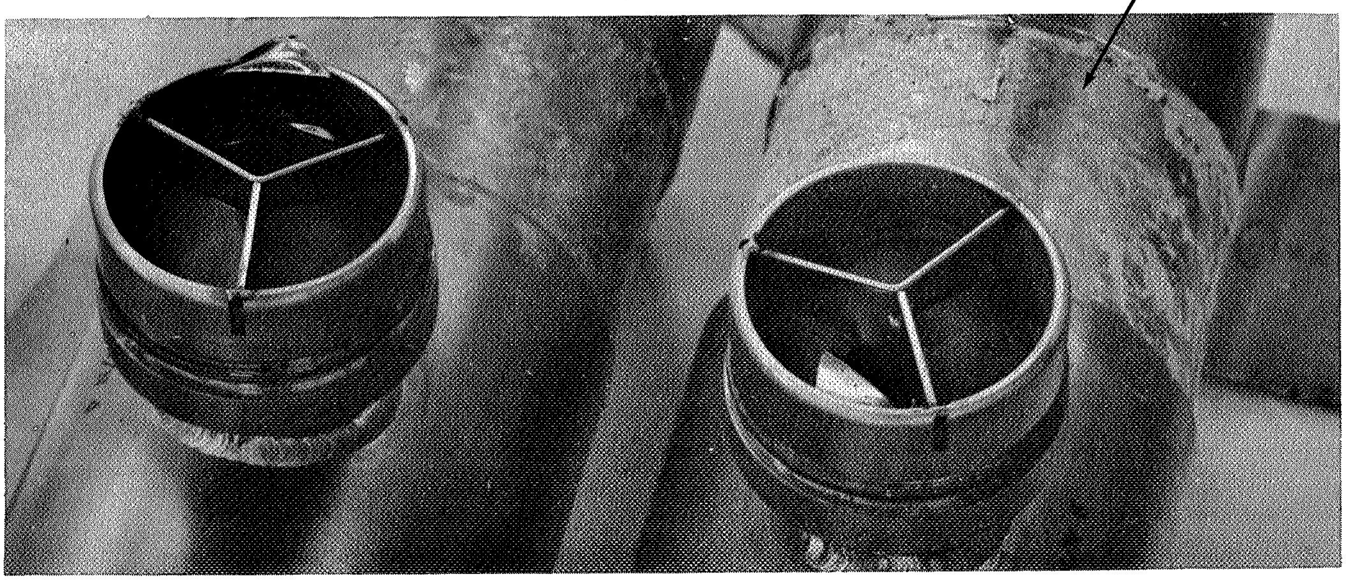
AMETEK/Calmec RDS-106-1 Burst Disc — Replaceable Assemblies
Burst Test Results

Figure 59. Burst Test - Calmec Replaceable Burst Discs



Note Complete Penetration Of Cutter Blade Into Burst Disc Diaphragm

Test
Manifold



Rated Burst Pressure — 33 psig
All Specimens Burst Within ±6 psig

Fike A 3857-1 Burst Disc — All Welded Units
Burst Test Results

Figure 60. Burst Test - Fike Burst Discs

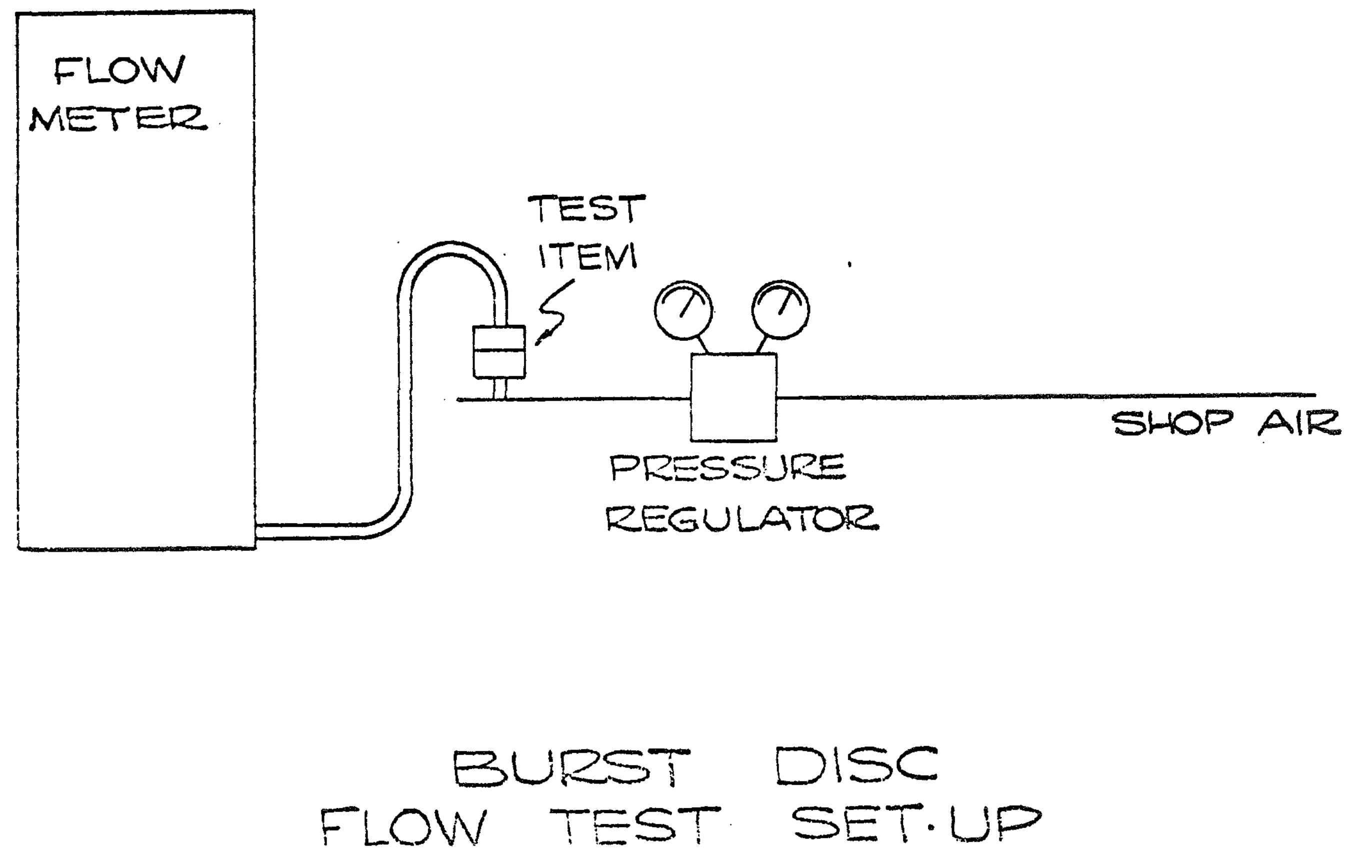


Figure 61. Burst Test Set-Up

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Burst — Date of Test: 11-7-69

Part Name: Burst Disc — Part Number: As Shown

Test Procedure: 8-480087 — Part Serial Number: As Shown

Test Pressure: As Shown — Test Media: GN_2 — Duration of Test: As Show

	Manufacturer	Serial Number	Remarks
1.	AMETEK/Calmec RDS-106	1	Burst — 41 psig — 8 min.
2.	AMETEK/Calmec RDS-106	2	Burst — 39 psig — 8 min.
3.	AMETEK/Calmec RDS-106	3	Burst — 39 psig — 8 min.
4.	AMETEK/Calmec RDS-106	4	Burst — 40 psig — 8 min.
5.	AMETEK/Calmec RDS-106	5	Burst — 41 psig — 8 min.
6.	AMETEK/Calmec RDS-106	6	Burst — 39 psig — 8 min.
7.	AMETEK/Calmec RDS-106	7	Burst — 43 psig — 8 min.
8.	AMETEK/Calmec RDS-106	8	Burst — 39 psig — 8 min.
9.	AMETEK/Calmec RDS-106	9	Burst — 41 psig — 8 min.
10.	AMETEK/Calmec RDS-106	10	Burst — 41 psig — 8 min.
11.	Fike A 3856	1	Burst — 24 psig — 5 min.
12.	Fike A 3856	2	Burst — 34 psig — 7 min.
13.	Fike A 3856	3	Burst — 26 psig — 5 min.
14.	Fike A 3856	4	Burst — 28 psig — $5\frac{1}{2}$ min.
15.	Fike A 3856	5	Burst — 37 psig — 7 min.
16.	Fike A 3856	6	Burst — 29 psig — 6 min.
17.	Fike A 3856	7	Burst — 29 psig — 6 min.
18.	Fike A 3856	8	Burst — 26 psig — 5 min.
19.	Fike A 3856	9	Burst — 32 psig — 6 min.
20.	Fike A 3856	10	Burst — 30 psig — 6 min.
21.			
22.			
23.			
24.			

Test Technician: S.H. Moore S/S — Test Engineer: V. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Burst — Date of Test: 11-7-69

Part Name: Burst Disc — Part Number: As Shown

Test Procedure: 8-480087 — Part Serial Number: As Shown

Test Pressure: As Shown — Test Media: GN_2 — Duration of Test: As Shown

	Manufacturer	Serial Number	Remarks
1.	Fike A 3857	1	Burst — 35 psi — 7 min.
2.	Fike A 3857	2	Burst — 35 psi — 7 min.
3.	Fike A 3857	4	Burst — 35 psi — 7 min.
4.	Fike A 3857	6	Burst — 39 psi — 8 min.
5.	Fike A 3857	7	Burst — 34 psi — 7 min.
6.	Fike A 3857	9	Burst — 30 psi — 6 min.
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			
21.			
22.			
23.			
24.			

Test Technician: S. H. Moore s/s — Test Engineer: J. Martinez

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Burst Pressure

Date of Test: 10-31-69

Part Name: Burst Disc

Part Number: Fike A 3856

Test Procedure: 8-480087

Part Serial Number: 11, 12, 13

Test Pressure: 20 psig

Test Media: GN_2

Duration of Test: 5 min.

Remarks

Each specimen reversed at 10 psi.

Rupture occurred at 20 psig.

Rated Pressure: 29 psig

Disc diaphragm was dented prior to test.

Test Technician: S. H. Moore S/S

Test Engineer: J. Martine

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test: Burst Pressure

Date of Test: 10-31-69

Part Name: Burst Disc

Part Number: AMETEK/Calmec RDS-106

Test Procedure: 8-480087

Part Serial Number: 11, 12, 13

Test Pressure: 37 - 39 psig

Test Media: GN_2

Duration of Test: 7 min.

Remarks

S/N 11 ruptured at 37 psig

S/N 12 ruptured at 39 psig

S/N 13 was damaged prior to test and reversed at 10 psi and ruptured at 23 psi.

Test Technician: S. H. MOORE S/S

Test Engineer: J. Martin

1.2.3.6.10 Flow Test

The determination of flow rate (Paragraph 5.7 of Test Procedure 8-480087) for the burst disc was accomplished by analysis.

The flow requirements for the burst disc as stipulated in the procurement specification is 350 SCFM. Analytically, it can be shown that a 1-inch diameter disc will flow approximately 400 SCFM. (This analysis is included in the Phase I Section of this report entitled "Burst Disc Sizing to Accommodate Vacuum Jacket Failure", dated 16 December 1968.)

The flow test was not conducted since burst disc obstructions to flow after rupture are almost non-existent with a pressurized annulus condition of 30 psig. The gas volume present at burst causes the snap-action and a complete peel-back of the diaphragm.

1.2.3.6.11 Liquid Air Flashing Test

Requirements

This test is conducted to simulate the flashing nature of liquid air in the vacuum annulus at burst disc rupture when it becomes superheated by a rapid pressure drop in the annulus immediately following burst disc rupture.

Procedure

A container of LN_2 was to be placed inside of a tank of a known volume and allowed to boil-off and pressurize the tank to an internal pressure of 30 psig. The container for the LN_2 was large in diameter with low side walls to allow splashing of the LN_2 on to the walls of the tank during venting. When the pressure reached 30 psig the vent valve was to be opened to rapidly vent the tank of all gas (GN_2). As the tank is venting down any increase in pressure was to be recorded.

Results

During this venting operation, no increase in pressure was noted that would be the result of exploding liquid as it came into contact with the warm tank walls. This test was repeated with two LN_2 container wall heights to insure that the container was not inhibiting the dispersion of the LN_2 at venting.

No pressure increase was noted during either test.

Data Sheets

For photographs of test set-up, see Final Report - Vacuum Seal Valve Task II, Paragraph 2.2.1.4.9 Pump Out - Contamination Test.

1.3 Procurement Specification

Procurement specifications were developed as a result of information gained from the phase I evaluation and the burst disc assembly testing.

NASA Specification No. 79K00108 has been assigned to the specification titled "Replaceable Burst Disc, Vacuum Jacketed Cryogenic Transer and Storage Systems." The all welded procurement specification has been assigned NASA No. 79K00109 and titled "All-welded Burst Disc, Vacuum Jacketed Cryogenic Transfer and Storage Systems." These specifications were written to be used as procurement criteria for hardware that will meet the design objectives of this study accomplished under NASA Contract No. NAS 10-6098.

1.4 CONCLUSIONS

A. The AMETEK/Calmec Burst Disc development program was successful in establishing several critical burst disc design parameters. These parameters included various combinations of materials which were tested in the burst disc assembly. Tests were conducted on the cutting capability of several different stainless steels in conjunction with the Nickel diaphragm material. It was found that 17-7PH afforded the superior cutting edge (See Paragraph 1.2 AMETEK/Calmec development report). TFE Teflon coating of the burst disc diaphragm (which was used by both AMETEK/Calmec and Fike) provides excellent corrosion resistance and according to the manufacturer is easy to apply and is consistent in producibility. Both the .0025 Nickel and .0015 Inconel 600 burst disc diaphragm tested performed well in meeting design requirements. Tests results indicate that the best repeatability in burst pressure was attained with the Inconel.

B. The Phase II test program has established the reverse buckling burst disc as a reliable unit. Burst pressure repeatability can be assured if the nominal pressure within the total pressure band is chosen as the design rated burst pressure of the disc diaphragm. Burst pressure tests have indicated that deviation in excess of $\pm$ 1 psi of the nominal pressure can result in burst pressures outside of the pressure allowable. To insure burst pressures within the tolerance specified ($\pm$ 5 psi) the disc should be designed to within $\pm$ 1 psi of the nominal burst pressure.

C. The two (2) configurations that were developed and tested indicate high reliability for field application. Both units are the "Reverse Buckling" type. One is the all-welded Fike Model RKB-A3857-1 and the other is the AMETEK/Calmec Replaceable Disc Assembly RDS-106. (The Fike model RKB-A3856-1 Replaceable Disc Assembly flat seat leaked excessively at rated seal load and should be redesigned to a conical seat in order to achieve recommendation for future procurement.

D. The cutter corrosion test was not conclusive for determining the effect of corrosion on the cutter piercing point. This test was conclusive, however, in determining that teflon coating over the entire surface was the least affected in salt fog test and is selected for future procurement of the cutter disc assembly. The Fike units, which were uncoated, showed no corrosion from salt fog test. Burst tests were completed with no evidence of blade cutter dullness. However, it must be noted that salt fog testing on all burst disc assemblies was accomplished with protective caps in place, while the cutters underwent salt fog testing completely exposed. Since a significant characteristic for proper performance of the reverse buckling disc is the piercing action which occurs as the diaphragm buckles, teflon coating of the cutter blade will insure that the cutter blade will exhibit the same cutting characteristics over the useful life of the assembly.

E. The burst disc assembly with a replaceable diaphragm combines features necessary to permit assembly in the field with little chance of damage and a permanent seal. The configuration of a welded cutter and bursting diaphragm is unique to this program and has yielded a cutter assembly that can easily be handled without damage. Since sealing is accomplished by line contact of contoured conical surfaces with slightly different radii, a light film of high vacuum grease (Apeizon) should be added to the sealing surface prior to assembly.

F. The determination by testing of required features to ensure extended reliable life has been verified. The features determined to be necessary to ensure extended reliable life is the selection of materials: (1) 304L CRES Body, (2) Teflon-coated Nickel 200 or Inconel 600 diaphragm, (3) Teflon-coated 17-7PH CRES cutter. The Teflon coat on the cutter is unique with this program. Teflon coating will provide the protection necessary to maintain the required point for extended reliable life (five years of more).

G. An early design objective was to provide protection on the inlet side of the disc in the form of a screen. However, during the development stages, a leakage free installation incorporating this protective device was not possible. During the early stages of the development program, dents on the inlet surface of the disc were evaluated and pulled out by the vacuum to determine the effect on burst tolerance. Tests indicated that the reverse buckling pressure can be cut by as much as two-thirds rated pressure. Development of a protective device or screen is recommended.

H. Extreme care should be taken in the use of the all-welded unit. Since the disc diaphragm is not removable during welding, the unit could receive weld spatter on the inner surface of the disc. This condition may not be evident during installation and could cause permanent damage to the diaphragm, affecting its burst tolerance, corrosion resistance and reliability.

I. The protective cap on the outlet (or vent port) of the burst disc is adequate for exposure to 1400°F flame for ten (10) seconds. However, it should be provided with a means for retaining it to the body when expelled. Only one (1) material was tested. No other material was found that the supplier would certify to the high temperature requirement. This material is Dow Corning "Silastic" Silicone.

J. The conical seat unit was superior to the flat seat. The seal on the conical seat is relatively unaffected by repeated uses or reinstallation where the Teflon seal on the flat seat does not stand up under repeated use.

K. It is recommended that all externally threaded disc retainer nuts be changed to internally threaded to eliminate the possibility of water entering the assembly when installed in the upside-down attitude. (The protective cap would then protect it while right side up).

L. Vacuum grease (Apeizon) was used successfully on the sealing surfaces of the disc assemblies and is recommended for future use. It is particularly helpful in protecting the Teflon sealing surface of the disc assembly.

1.5 RECOMMENDATIONS

A. A program to determine the service life of vacuum grease on the sealing surface of the burst discs is recommended. This material has been very successful in preventing leakage, damage to sealing surface, and lowering of high torques in order to seal. However, more information is needed relative to its service life when exposed to the environment at a launch complex at Kennedy Space Center.

B. The future development of a protective screen for the inlet of the burst disc is recommended. Effort in this area was made during the AMETEK/Calmec development program, but problems with sealing with the device attached resulted in this effort being inconclusive. Damage did occur on the inlet surface of the discs tested and this damage potential has to be eliminated if a burst pressure tolerance is going to be a reliable feature of burst discs.

C. The analytical approach to pre-determining reverse buckling diaphragm parameters requires more tests be made in the area of forming diaphragms of various dimensions and materials. This will add empirical data that will ensure higher degree of accuracy in the analytical approach.

1.6 APPENDIX

A. Burst Disc Analysis

(1) Sizing Burst Disc for .010 Square Inch Failure Area

(2) Burst Disc - Vacuum Jacket Failure

(3) Burst Disc Sizing - Various Line Sizes

This analysis was performed to evaluate one failure mode. The conclusion reached for this failure mode may not be the controlling factor for the final burst disc sizing. Additional failure modes will be analyzed to determine the controlling requirement for burst disc sizing.

The size of the burst disc for the following failure mode analyzed is dependent on the maximum crack size or weld porosity defect that could occur, short of a catastrophic failure. At AMETEK/Straza we have experienced no fatigue crack failures, weld cracks, or weld porosity exceeding .010 square inch. Accordingly, this analysis is based on the gas that can be vaporized from the fluid flowing through a .010 square-inch area at operating line pressure.

Reference: "Flow of Fluids Through Valves, Fittings and Pipe," Crane Technical Paper No. 410, Pages 3-4.

Equation 3-19 for liquid flow:

$$(1) \qquad W = 1891\, d_L^{\,2} \sqrt{\frac{\Delta P_L}{K_L V_L}}$$

Equation 3-20 for gas flow:

$$(2) \qquad W = 1891\, d_g^{\,2} \sqrt{\frac{\Delta P_g\, \ell_g}{K_g}}$$

Where:

- W = Rate of flow in pounds per hour
- d = Internal diameter of pipe in inches
- P = Pressure in psig
- K = Resistance coefficient
- $\bar{V}$ = Specific volume of fluid in Ft^3/Lb
- ℓ = Weight density of fluid, lbs/ft^3
- Δ = Differential between two points

Combining equations (1) and (2) and solving for d_g:

$$(3) \qquad 1891\, d_g^{\,2} \sqrt{\frac{\Delta P_g\, \ell_g}{K_g}} = 1891\, d_L^{\,2} \sqrt{\frac{\Delta P_L}{K_L\, V_L}}$$

(4) $$d_g = d_L \sqrt{\frac{\Delta P_L \; K_g}{K_L \; V_L \quad P_g \; \ell_g}}$$ Diameter of orifice in inches

d_L = 4 hydraulic radii of a crack .010" wide x 1.0" long

= 4 x .010

= .040 inches^2

$K = f \frac{L}{D}$ where:

f = Friction factor
L = Length in feet
D = I.D. of pipe in feet

Assume $K_L = .50 \quad K_g = .80$

Therefore:

(5) $$d_g = .040^4 \sqrt{\frac{.80}{.50}} \sqrt{\frac{\Delta P_L}{V_L \; \Delta P_g \; \ell_g}}$$

$$= .045 \sqrt{\frac{\Delta P_L}{V_L \; \Delta P_g \; \ell_g}}$$

Assume a liquid oxygen (LO_2) line 8" dia. x sched. 5 pipe leaks into the vacuum annular space. The mean gas temperature in the annulus $T_M = 110^oF$ or 350^oR

The gas exit velocity is expressed as:

$V_S = \sqrt{K_g \; R \; T}$ Where:

V_S = Sonic Velocity in ft/sec.
R = Individual gas constant
T = Absolute temperature in ^oR

$V_S = \sqrt{1.4 \times 32.2 \times 53.5 \times 570}$

= 870 ft/sec

(6) Solving for $\Delta P_L = \frac{3.62 \; K_L \ell \; q^2}{d_L^4}$ Where: q = FLOW FT^3/SEC

Assume $q^2 = 500 \text{ GPM} \times \frac{.010}{55.5} \times \frac{231}{1728} \times \frac{1}{60}$

= .002 ft^3/sec leakage of LO_2

$\ell = \frac{1}{V_L} = 71.17 \text{ lb/ft}^3 \; LO_2$

Therefore:

$$\triangle P_L = \frac{3.62 \times .50 \times 71.17\ (.002)^2}{(.040)^4}$$

$= 2.0$ psi pressure drop through crack

(7) Solving for $\triangle P_g = 107.8 \times 10^{-6}\ K_g\ \rho_g\ v^2$

$\rho_g = \frac{PV}{RT}$ Assume: $P = 45$ psia
$V = 1.0$ ft/min

$R = \frac{1544}{M}$ Where: M = molecular weight

$= \frac{1544}{32}$

$= 48.25$

$T = 350^{\circ}R$ Therefore:

$$\rho_g = \frac{45 \times 144 \times 1.0}{48.25 \times 350}$$

$= .384\ lb/ft^3$ density of GO_2 at approximately $-110^{\circ}F$ and 45 psia gas pressure in the vacuum annulus

$$\triangle P_g = 107.8 \times 10^{-6} \times .80 \times .384\ (.870 \times 10^3)^2$$

$= 25.06$ psi pressure drop of gas flow through burst disc orifice

(8) $$d_g = .045\ \sqrt[4]{\frac{2.0 \times 71.17}{25.06 \times .853}}$$

$= .072$ in. dia. burst disc orifice will accommodate the gas flow through a .010 sq. in. crack

AMETEK / Straza

ENGINEERING REPORT

NO: Appendix - Item B1

SUBJECT: Sizing Burst Disc for .010 Square-Inch Orifice Area

DATE: November 13, 1968

PAGE ____ OF ____

BY: C.Urbanac CHECKED: ____

JOB NO: NAS10-6098

SUMMARY:

The preceeding analysis is based on gas flow which requires a much smaller orifice diameter. The cost of installing a small burst disc would be the same as one that is at least as large as .500 inches in diameter. Therefore, for conservatism, it is recommended that a burst disc of .500 inch diameter be used to accommodate the gas flow for a line failure of this size (.010 sq.in). The .500 inch diameter burst disc is approximately 48 x larger than the calculated diameter of .072 inches diameter.

The approximate flow rate through a .500 inch diameter orifice is:

$$Q = \frac{.50^2\pi/4}{144} \times 870 \times .60$$

$$= 0.71 \text{ ft}^3/\text{sec (with orifice coefficient C = .60)}$$

NOTE: Since all failure modes have not been analyzed, a 1.00 inch diameter disc will be required as preliminary design for vendor coordination purposes.

AMETEK / Straza

ENGINEERING REPORT

SUBJECT: Burst Disc Sizing to Accommodate Vacuum Jacket Failure

BY: C. Urbanac CHECKED:

NO: Appendix - B2

DATE: December 16, 1968

JOB NO: NAS10-6098

INTRODUCTION:

This investigation will determine what the effective size of the burst disc should be, to safely discharge accumulated air from the annulus of a leaking vacuum jacketed line. The most reasonable assumption for leakage into the annulus will be based on a hole .010 square inch in area in the vacuum jacket of an LH_2 line.

DESCRIPTION OF PROBLEM:

The LH_2 line will be covered with at least ten layers of aluminized mylar. These are radiation insulators that will provide thermal resistance to heat flux input into the LH_2 line. Also, when the line is being purged with warm gas it will reduce the heat flux into the annulus. Test results published by National Research Corporation indicated a temperature of $540^{\circ}R$ on the first external layer of 70 layers per inch of their insulation in a vacuum of 10^{-4} mm Hg. When the vacuum is broken by the inrush of air through a vacuum jacket opening, all the moisture in the air will form condensed frost on the cold insulation. Some of the air in the annulus will penetrate the insulation and will drop the surface temperature of $425^{\circ}R$ at the first outer layer of the insulation by increasing the conductivity through the insulation while the remaining air in the annulus will be conducting more heat flux from the vacuum jacket tending to <u>raise</u> the insulation temperature.

The air penetrating the insulation will be liquified, forming high conductive films that will have a thermal conductivity as high as .088 $\frac{B}{HR-{}^{\circ}F-FT^2}$ for liquid nitrogen versus .0088 $\frac{B}{HR-{}^{\circ}F-FT^2}$ for gaseous air at a mean temperature of $300^{\circ}R$ (Ref: Wadd Technical Report 60-56, Part 1). Liquid air trapped under the mylar insulation will become slush and solid frozen air. Liquid air condensing on the curved surface of a horizontal line will run off due to gravity effects. On a vertical line, the liquid air will drip off and hit the vacuum jacket elbow, bayonet joint, or bulkhead cone in the annulus. Practically all of the swing arm assemblies are horizontal which means that if a failure occurred, it would most probably be on a horizontal arm where the liquid air would drip off, hit the vacuum jacket, get boiled off into gaseous air, then become reliquified after contact with the mylar insulation containing the frozen air.

Solving for the heat transfer through the vacuum jacket with the following assumptions:

1. Vacuum jacket has frosted to a thickness of .215 inches of H_2O due to the cycles of liquification and vaporization occurring when the air leaking into the annulus is condensed on the inner line, flows off, then is vaporized when it hits the inner surface of the vacuum jacket. Equilibrium time of three hours (Ref: "Cryogenic Technology" by Vance, P. 179) to obtain the .215" thickness.

2. Assume that five feet of vacuum jacket on each side is also conducting heat into the 20-foot line for a total effective length of 30 feet, exposed to convective air currents.

3. Assume the annulus mean air temperature is $164^{O}R$ and the heat input vaporizes the liquid air impinging on the vacuum jacket.

4. Assume heat flux resulting from radiation is negligible.

5. Assume that frost thermal conductivity is 2.25×10^{-2} $\frac{B}{HR-{}^{O}F-FT^{2}}$ at a mean temperature of $-180^{O}F$. Ref: "Cryogenics Technology" by Vance, P. 179.

$$Q = \frac{\Delta T \quad 2\pi}{\frac{1}{r_i \bar{h}_i l_{20}} + \frac{\ln r_2/r_1}{k_1 l_{20}} + \frac{\ln r_3/r_2}{k_2 l_{20}} + \frac{\ln r_4/r_3}{k_3 l_{20}} + \frac{\ln r_5/r_4}{k_4 l_{20}} + \frac{\ln r_6/r_5}{k_5 l_{20}} + \frac{1}{r_6 h_0 l_{30}}}$$

LH_2	Inner Line	Alum Mylar & Liq. Air	Annulus Air	Vac. Jacket	Frost	Amb. Air

Let $\bar{h}_i = 0$

$\Delta T = 580 - 37 = 543$

$l_{20} = 20$ ft $l_{30} = 30$ ft

$r_1 = 4.203$ in.

$r_2 = 4.312$ in.

$r_3 = 4.323$ in.

$r_4 = 5.241$ in.

$r_5 = 5.375$ in.

$r_6 = 5.590$ in. or .466 ft.

$k_1 = 1.0 \ \frac{B}{HR-{}^{O}F-FT^{2}}$ for 304 cres

$k_2 = .0720$ for frozen air combined value of N_2 and O_2

Ref: Cryogenic Eng. News, January 1967, Pgs. 110 and 112

$k_3 = .0087 \ \frac{B}{HR-{}^{O}F-FT^{2}}$ Assumed thermal condition of air at $297^{O}R$ (Ref: Wadd T.R. 60-56, Part 1, Pg. 3.006)

k_4 = 8.0 for 304 cres at 400°R (Reference Cryogenic Materials Data Handbook)

k_5 = $.069 \frac{B}{HR-{}^{o}F-FT^2}$ for frost mean T = 400°R

(Extrapolated from Cryogenics Technology by Vance, Page 179)

h_o = $1.00 \frac{B}{HR-{}^{o}F-FT^2}$ Assumed value of convection for air outside vacuum jacket

T_W = 580°R $T_C = 37\,^{\circ}R$

$$Q = \frac{(580-37)\ 2\pi \times 20}{\underset{LH_2}{O} + \underset{\substack{LH_2\\ Line}}{\frac{l_n \frac{4.312}{4.203}}{1.0}} + \underset{\substack{Mylar\ \&\\ Slush\ Air}}{\frac{l_n \frac{4.323}{4.312}}{.0720}} + \underset{Air}{\frac{l_n \frac{5.241}{4.323}}{.0087}} + \underset{Vac.\ Jkt}{\frac{l_n \frac{5.375}{5.241}}{9.10}} + \underset{Amb.\ Air}{\frac{l_n \frac{5.590}{5.37}}{.069}} + \underset{Ambient\ Air}{\frac{1}{.466 \times 1.0 \times 1.5}}}$$

$$Q = \frac{68.930}{.0256 + .0352 + 22.1326 + .0030 + .5684 + 1.4306}$$

$$= 2849 \frac{B}{HR} \text{ Heat Flux Input}$$

CHECK: Solving for the mean annulus air temperature X_1 at the mean annulus radius = 4.782 in.

$$\frac{(580 - X_1)\ 2\pi \times 20}{\frac{l_n \frac{5.241}{4.782}}{.0087} + \frac{l_n \frac{5.375}{5.241}}{9.10} + \frac{l_n \frac{5.540}{5.375}}{.069} + \frac{1}{.466 \times 1.0 \times 1.5}}$$

$$= 2849$$

$$X_1 = \frac{-2849\ (10.5333 + .0030 + .5684 + 1.4306}{125.664} + 580$$

$$= +\ 296^{o}R \text{ or } -164^{o}F$$

CHECK: Temperature on surface of Mylar and trapped frozen air covering the LH_2 line.

$$X_2 = \frac{-2849\ (22.1326 + .0030 + .5684 + 1.4306}{125.664} + 580$$

$$= 33^{o}R$$

The following analysis is based on the assumption that the temperature gradient of $33^{o}R$ at the LH_2 line and $296^{o}R$ at the mean diameter of the annulus covering a distance of .46 inches is not realistic. Therefore, the more realistic assumption would be to assume the annulus has filled up with solid and slush air with

$$k = .072 \frac{B}{HR\text{-}^{o}F\text{-}FT^2}$$

$$Q = \frac{68930}{.0256 + \dfrac{l_n \dfrac{5.241}{4.312}}{.072} + .0030 + .5684 + 1.4306}$$

Mylar & Slush — Vac. Jkt. — Frost — Ext. Air

$$= 14{,}550 \frac{B}{HR} \text{ Heat Flux through solid and slush air}$$

CHECK: Mean annulus temperature at 4.782 in. radius

$$X_{11} = \frac{-14550}{125.664}\left(\frac{l_n \dfrac{5.241}{4.782}}{.072} + .0030 + .5684 + 1.4306\right) + 580$$

= $201^{o}R$. This value is higher than $163^{o}R$, the boiling point of liquid oxygen, also higher than $140^{o}R$, the boiling point of liquid nitrogen. Solid or slush air cannot exist at this temperature at 14.7 psi.

From the above, the original assumption that liquid air and some slush would form on the LH_2 line, then drain off and fall on the bottom of the vacuum jacket, appears to be valid. This liquid and slush would be vaporized, then recondensed. For conservatism, we will assume that all the heat transferred per hour is recycling the liquid air at one cycle per hour.

W = Amount of liquid air recycled per hour

= Q/N

ν = Heat of vaporization for liquid air

$= 86.1 \frac{B}{HR}$

$$W = \frac{2849}{86.1}$$

= 33.1 lbs/hr assumed amount of liquid air being recycled.

$\sum W$ = Lbs of air in the annulus

$$= \left[20 \times \pi/4 \left(\frac{\overline{10.482}^2 - \overline{8.646}^2}{144}\right) - \frac{22.60}{54.27}\right]\rho + 33.10$$

Recycled Air

ρ = .134 lbs/ft^3 Air density at a mean temperature of 296°R & 14.7 psi

$\sum W$ = $[3.831 - .416]$ .134 + 33.10 = .50 + 33.10

= 33.60 lbs of air (.50 lbs of gas + 33.10 lbs of liquid at a mean temperature of 164°R)

V_A = Annular Volume

$$= \left(\frac{\overline{10.482}^2 - \overline{8.625}^2}{144}\right) \pi/4 \times 20$$

= 3.870 ft^3 total

V_{A1} = Annular Volume less Liquid Volume

$$= 3.870 - \frac{33.60}{54.27 \text{ lb/ft}^3} \quad (LO_2 + LN_2)$$

= 3.250 ft^3 Gas Volume

Solving for the amount of gas required to be boiled off, to burst the disc.

w = $\frac{PV}{RT}$ - .50 (lbs of gas in annulus)

P = 30 x 144 T = 296°R Mean Temperature of Annulus

= 4320 P.S.F. Burst Pressure

V = 3.450 Ft^3

R = 53.34 ft.-lb F/Lb M - $^{\circ}$R Gas Constant for Air

$$w = \frac{4320 \times 3.250}{53.34\ (296)} - .50$$

= .39 lbs of liquid air must be vaporized to raise the annulus pressure to 30 psig and to burst the disc.

H = Heat of vaporization to reach 30 psig

= 86.1 x .39

= 33.6 B Heat Input to raise the pressure to 30 psi

Heat input into annulus when purging with 70°F gas in LH_2 line and assuming 120°F air outside of vacuum jacket. Assume $h_1 = 1.0 \frac{B}{HR\text{-}^{\circ}F\text{-}FT^2}$ for purge gas and equilibrium conditions.

$$\Sigma Q = \frac{(530 - 301)\, 2\pi \times 20}{\frac{12}{4.203 \times 1} + \frac{1}{n}\frac{\frac{4.312}{4.203}}{9.1} + \frac{1}{n}\frac{\frac{4.323}{4.312}}{.072}} + \frac{(580 - 301)\, 2 \times 20}{\frac{1}{n}\frac{\frac{5.375}{5.241}}{9.1} + \frac{1}{n}\frac{\frac{5.590}{5.375}}{.069} + \frac{1}{.466 \times 1.5}}$$

$= 9947 + 17{,}513$

$= 27460 \frac{B}{HR}$ Internal and external heat flux input when purging

Time to Raise Annulus Pressure to 30 psig
This ignores Heat Absorbed by Lines, Insulation and Frost

$$T \simeq \frac{H}{Q}$$

$$= \frac{33.6}{27{,}460} \times 3600$$

= 4.4 seconds (approximately four seconds to burst disc and allow for bleed-off occurring at failed section of vacuum jacket)

Time to complete boil-off after disc bursts.

$$T_{BO} = \frac{(W-w)h}{27{,}460} \times 60 = \frac{(33.10 - .39)\, 86.1}{27{,}460}\, 60$$

= 6.15 minutes to boil off liquid air

Solving for the volume of air at S.T.P. conditions.

$$\text{Volume } V_{STP} = \Sigma W \text{ Lbs} \times \frac{v}{LB}$$

$$\text{Vol. of 1 cu.ft.} = \frac{1}{.07651}$$ Ref: Fluid Mechanics - Binder 3rd Ed., P. 28

$$V_{STP} = \frac{33.6}{.07651}$$

$= 439 \text{ Ft}^3$ at S.T.P.

Volume at 296°R with an air density of .408#/cu.ft. at 30 psig.

$$V_{301} = \frac{33.1}{.408} + 3.250$$

$= 84.4 \text{Ft}^3$ of air at 296°R mean annulus temperature

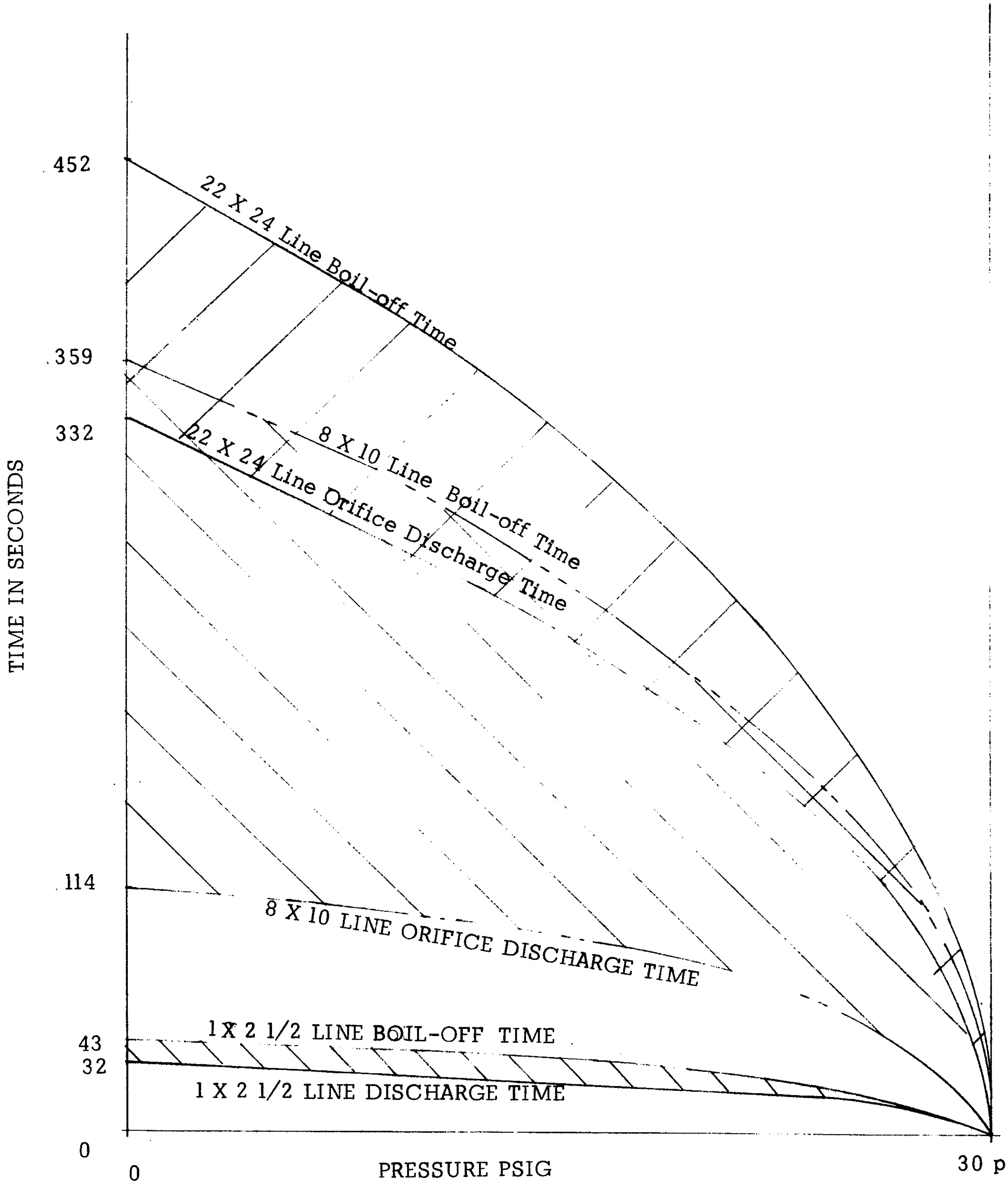
At this volume of 84.4 Ft^3 of air in a 20-foot length of vacuum jacket and at a burst pressure of 30psig, a one-inch diameter burst disc orifice is adequate. From Crane Technical Paper No. 410, "Flow of Fluids," Pages 3-25, with an orifice coefficient of 1.003 (turbulent flow) and an expansion factor Y of .774, the orifice can flow 4.91 cubic feet initially, then decay to zero in 6.15 minutes. At sonic velocity with Δ P/P of approximately .5 PSI for 6.15 minutes, the total flow capability is 6.15 X 60 X 4.91 which equals 1813 cubic feet.

The purpose of this analysis was to size the rupture discs needed in the event the vacuum jacket leaked, permitting air to liquify on the liquid hydrogen line. The air will collect in all three phases gas, liquid and slush. Upon cessation of liquid hydrogen flow, and at the start of nitrogen gas purge of the inner line, the liquid and slush air will begin to vaporize. The first air component boiled off will be nitrogen, followed by practically pure oxygen. This oxygen is highly explosive and, if it contacts a non-compatible material, it can implode the line.

The analysis method used in the following pages was outlined in Progress Report No. 3. It established parameters of 120^{o}F ambient air temperature and 70^{o}F for the nitrogen gas purge. These parameters indicate a fairly constant heat input rate q in B/IR-FT^{2}, reference Page 6. Several assumptions were made in the analysis: The liquid air and slush being recycled by the heat input into the vacuum jacket was assumed to be equal to the ambient boil-off of the vacuum jacket; secondly, steady state conditions were also assumed during purge, which would make all the boil-off time rates slightly longer. No allowance was made for the heat input into the LH_2 line and the vacuum jacket during purge. The line lengths used were based on a twenty- (20) foot line.

The results of the analysis on Pages 2 and 6 indicate the one- (1.0) inch diameter burst disc is adequate to safely relieve any line size from 1 x 2 1/2 to 22 x 24. In all three examples used, the gas generation or boil-off rate is much slower than the orifice discharge rate. If design criteria is to be based on the vacuum jacket leakage and the heat flux is kept at the values shown on Page 4, and the line length restricted to twenty (20) feet or less, it is advisable to standardize on the one- (1.0) inch diameter rupture disc orifice.

The size of the burst disc is strictly dependent on the heat flux input at purge, and independent of the amount of slush air to be boiled off.


452
359
332
114
43
32
0
TIME IN SECONDS
22 X 24 Line Boil-off Time
8 X 10 Line Boil-off Time
22 X 24 Line Orifice Discharge Time
8 X 10 LINE ORIFICE DISCHARGE TIME
1 X 2 1/2 LINE BOIL-OFF TIME
1 X 2 1/2 LINE DISCHARGE TIME
0
PRESSURE PSIG
30 p

Line Size	Inner Line Inside r_1	Inner Line Outside r_2	Outer R. Liq. Air r_3	Vacuum Jacket r_4	Vacuum Jacket r_5	Outer Frost r_6
22 x 24	10.750	11.000	11.012	11.750	12.000	12.215
20 x 22	9.750	10.000	10.762	10.750	11.000	11.215
16 x 18	7.812	8.000	8.012	8.750	9.000	9.215
14 x 16	6.812	7.000	7.012	7.812	8.000	8.215
12 x 16	6.219	6.375	6.387	7.812	8.000	8.215
10 x 12	5.241	5.375	5.387	6.219	6.375	6.585
8 x 10	4.203	4.312	4.323	5.241	5.375	5.540
6 x 8	3.204	3.312	3.324	4.203	4.312	4.527
4 x 6	2.167	2.250	2.262	3.204	3.312	3.527
3 x 5	1.509	1.750	1.762	2.673	2.782	2.997
2 x 4	1.123	1.188	1.200	2.167	2.250	2.465
1 1/2 x 3	.885	.950	.962	1.667	1.750	1.965
1 x 2 1/2	.593	.658	.670	1.354	1.437	1.652

Inner Line

Line Size	$\frac{\ln r_2/r_1}{1.0}$ (1)	$\frac{\ln r_3/r_2}{.0720}$ (2)	$\frac{\ln r_4/r_3}{.0087}$ (3)	$\frac{\ln r_5/r_4}{9.10}$ (4)	$\frac{\ln r_6/r_5}{.069}$ (5)	$\frac{12}{1.5 \times 1.0\ r_6}$ (6)
22 x 24	.0222	.01506	7.45429	.00231	.25712	.65493
20 x 22						
16 x 18						
14 x 16						
12 x 14						
10 x 12						
8 x 10	.0256	.0352	22.1326	.0030	.5684	1.43112
6 x 8						
4 x 6						
3 x 5						
2 x 4						
1 1/2 x 3						
1 x 2 1/2	.10400	.25078	80.29567	.00653	1.89400	4.84261

Line Size	$Q = \frac{68930}{\Sigma (1)+(2)+..(6)}$ B/Hr	$W^* = \frac{Q}{86.1}$ Lbs/Hr Liq. Air (Slush)	V_1 4365 $(r_4^2-r_3^2)$ Annulus vol. FT^3	$V_2 = \frac{W}{54.27}$ Ft^3 Liq. Air	$V_3 = V_1-V_2$ Net Ann. Vol. FT^3	$w_A = V_3 \times .171$ lbs of gaseous air in Ann. at 14.7 psi
22 x 24	8200	95.24	7.332	1.755	5.577	.954
20 x 22						
16 x 18						
14 x 16						
12 x 14						
10 x 12						
8 x 10	2849	33.10	3.832	.610	3.222	.549
6 x 8						
4 x 6						
3 x 5						
2 x 4						
1 1/2 x 3						
1 x 2 1/2	789	9.16	.604	.169	.435	.074

*NOTE: "W" is slush and liquid air assumed to equal the total boil-off capability of the vacuum jacket.

AMETEK / Straza

ENGINEERING REPORT

NO: Appendix - B3

SUBJECT: Burst Disc Sizing

DATE: March 31, 1969

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BY: C. Urbanac CHECKED:

JOB NO: NAS10-6098

Line Size	$\frac{12}{r_1}$ (7)	$\frac{\ln r_2/r_1}{9.1}$ (8)	$\frac{\ln r_3/r_2}{.072}$ (9)	$Q_{1P} = \frac{4\pi(530-301)}{(7)+(8)+(9)}$ B/HR Purge Heat at 70°F	$Q_{2P} = \frac{4\pi(580-301)}{(4)+(5)+(6)}$ B/HR Amb. Heat at 120°F	$\Sigma Q = Q_{1P} + Q_2$ Purge & amb. Heat Input B/HR
22 x 24	1.11627	.00252	.01506	25,380	38,344	63,724
20 x 22						
16 x 18						
14 x 16						
12 x 14						
10 x 12						
8 x 10	2.85510	.00281	.03523	9,947	17,513	27,460
6 x 8						
4 x 6						
3 x 5						
2 x 4						
1 1/2 x 3						
1 x 2 1/2	20.23608	.01142	.25192	1,404	5,199	6,603

Line Size	w_{B0} = lbs. of gas required to raise ann. press. to 30 psig $= \frac{PV_3}{RT} = .408V_3$	H_{30} = Heat Req'd to pressurize annulus to 30 psig, ignoring heat absorbed by lines, insulation and frost $H_{30} = 86.1 (w_{bo} - w_{\varepsilon})$	T_{30} = Time in SEC to pressurize annulus to 30 psig $T = \frac{3600\ H_{30}}{\Sigma Q}$
22 x 24	2.275	113.77	6.43
20 x 22			
16 x 13			
14 x 16			
12 x 14			
10 x 12			
8 x 10	1.315	66.00	8.65
6 x 8			
4 x 6			
3 x 5			
2 x 4			
1 1/2 x 3			
1 x 2 1/2	.099	2.15	1.17

Line Size	$W_{BO} = W - w_{BO}$ boiloff after disc ruptures IN LBS.	$T_{BO} = \frac{3600 \times 86.1\, W_{BO}}{\Sigma Q}$ Time to boiloff in seconds assuming steady state conditions	$T_{DISC} = \frac{W_{BO}}{.28}$ sec to discharge annulus thru 1" dia. orifice at steady state & at 30 psig Ref Pgs 6, 7 & 8	$q = \frac{\Sigma Q}{\text{Surface area Vacuum Jkt}}$ B/Hr-Ft^2 Heat input ck
22 x 24	92.965	452	332	531
8 x 10	31.785	359	114	488
1 x 2 1/2	9.061	43	32	466

Crane Nomograph Values

1. $R = 53.34$ Gas constant for air Ft-Lb F/LBM - ^oR
2. $P = 30.0 + 14.7 = 44.7$ psi internal pressure
3. $\frac{\Delta P}{Pi} = \frac{30}{44.7} = .671$
4. Try $d_1 = 1.00$ in.
5. Try $\frac{do}{d_1} = 8$ max.
8. $\therefore$ Y = .68 from Page A-20
9. $\rho = \frac{PV}{RT}$ Density at an assumed mean temperature of 296^oR

$$= \frac{44.7 \times 144 \times 1.0}{53.34 \times 296}$$

$$= .408 \text{ lbs/ft}^3$$

10. C = .60 when $R_e = 4.34 \times 10^6$, Page A-19

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